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By Charles T. Brues.

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During a sojourn of several weeks in the Yellowstone National Park in the summer of 1923 the writer became interested in the fauna of the abundant thermal springs in that region. A considerable amount of material was obtained at that time and this has already been discussed in a paper published in 1924, together with a brief resumé of what had been previously recorded concerning the fauna of hot springs in other parts of the world. At that time he was surprised at the dearth of knowledge relating to the animal life of the numerous hot springs which are scattered through several of our other western states, and determined to investigate some of these when an opportunity might present itself. Plans were made to visit a number of hot springs in New Mexico, Nevada, California and Utah during the summer of 1927 and an itinerary was arranged to include as extensive and varied a series of springs as appeared possible in the limited time at our command. To further the purposes of the expedition he was given a grant from the Milton Fund for Research at Harvard University, which he wishes gratefully to acknowledge as this made it possible to extend the survey considerably.

In order to indicate more clearly the location of the hot springs to be mentioned, the accompanying outline map has been prepared. On it each spring is indicated by a dot together with a number by which the spring will be designated in the discussion which follows.

Some of these springs were first mentioned in publications of the United States Geological Survey; particularly in the reports of the early explorations of the west or of surveys made to locate routes for transcontinental railways. Very few references to them appear in any more recent publication, with the exception of those contained in certain water supply papers issued by the U. S. Geological Survey. Aside from their scientific interest these springs were naturally of considerable importance to these early explorers as the patches of green vegetation commonly associated with them in this desert region form conspicuous landmarks in an otherwise monotonous

[1] Contribution from the Entomological Laboratory of the Bussey Institution, Harvard University, No. 292.

country and the grass furnished much needed forage for their horses. Also the water when cool is usually fairly palatable. In some cases springs which we visited in 1927 were carefully described about 75

FIGURE 1. Map showing location of hot springs visited. The numbers are those cited in the descriptions and used elsewhere in the text.

years previously and it has been possible to indicate some changes which have taken place during this quite considerable interval of time.

From the naturalist's standpoint and from that of the nature-lover as well it is distressing to record that all except the most inaccessible springs, or those included within the boundaries of National Parks, have been either converted into natatoria, sanatoria for arthritics, radium baths and the like, or have been diverted into irrigation ditches, sometimes with the aid of dynamite, to supply a few desolate ranches with water for cattle and alfalfa. For this reason the fauna and the flora of these thermal springs is destined soon to be wiped out over considerable areas by the advance of commercialism.

As it is possible to approach most of the localities to be described over roads passable under ordinary weather conditions to automobiles we traveled by motor, carrying the necessary supplies and

camp equipment, journeying somewhat over 11,000 miles in this way.

The writer was accompanied by his wife who made collections of the grasses growing in and adjacent to the various hot springs, and observations on the temperatures and other conditions determining the growth of these plants. The results of these studies will be published separately. Determinations of the temperatures, specific gravity and hydrogen ion concentration of the waters where collections were obtained were made by my son, Austin M. Brues, and these data are included in the detailed account which follows. To both companions I am deeply indebted for their unfailing cheerfulness and resourcefulness under many trying circumstances.

For temperature, a thermometer was used which read to tenths of a degree centigrade.

For determining specific gravity, a hydrometer was used which read to the fourth decimal place. This determination had then to be corrected to a uniform temperature of 15° C., which introduced a certain error. On a basis of determination of the same water at different temperatures, we should consider this error to be not over 0.0004.

The hydrogen-ion concentration was determined by the colorimetric method. The following indicators were used, with their ranges expressed in pH; Bromphenol blue, 3.0–4.6; methyl red, 4.4–6.0; bromcresol purple, 5.2–6.8; phenol red, 6.8–8.4; cresol red, 7.2–8.8; thymol blue, 8.0–9.6. It would have been impracticable to carry liquid standards of comparison, so a color chart was used. This chart was issued by a German seedsman, and contained about 450 lithographed blocks of color. This included all the noticeably different pure colors from yellow through red to blue, about 24 in number, with a series of different intensities and brightnesses corresponding to each color, so that the pure color qualities of a given indicator would be read as equal if greater or less amounts of indicator were used, and in water of white, gray or black turbidity. The color chart was calibrated by means of chemical solutions, and differential readings of the same water using different amounts of indicator showed that the error could nowhere be over 0.4, and that where the ranges of two indicators overlapped the error could not be more than 0.1. The charts retained their original colors throughout the summer.

In practically all of the areas where active hot springs occur, there are evidences of the vast extent and enormous size of earlier springs now extinct. By reason of the chalky white or characteristically colored deposits produced by calcareous hot springs and the equally

distinctive sinter cones and formations resulting from the flow of siliceous springs it is possible readily to recognize the remains of extinct hot springs as features of the landscape, especially in connection with the non-conformity of the thin layers composing them which is always to be noted as a conspicuous feature.

The first of these which we encountered was a few miles southeast of the town of Beatty, Nevada, near the California state line and almost directly east of Death Valley, and it is typical of a quite recently extinct hot spring. Remains of a central elevation some thirty feet high slope off into the surrounding flat sage brush plain and there are indications of terraced slopes greatly eroded and washed away. As the pure white calcareous material becomes disintegrated it separates into very minute particles which are washed out by the spasmodic, torrential showers and form a covering of powdery, white soil. This extends for half a mile or more toward the lower part of the valley, and probably overlies similar deposits laid down when the spring was actively flowing. In this neighborhood are a number of others, each visible from a considerable distance as a white scar on the steeply sloping side of the low mountain ridge which borders the northern side of the valley. These are much more extensively eroded and evidently antedate the one first mentioned. Such groups are common throughout the hot springs area to be described, but they are frequently seen at places where no active nor very recently extinct springs occur within many miles, almost always they set well up on the slopes of hills or mountains. How many may have been present at lower levels, which have been smoothed down and covered with deposits derived from the higher slopes it is impossible to judge without more careful examination, but it is probable that those at the lower levels would rapidly disappear from view.

In one locality, particularly, an extensive group of large extinct hot springs is a conspicuous feature of the dull drab gray landscape, in an open valley well removed from any mountain slopes. These are about 35 miles south of the town of Denio, Oregon which is on the Nevada state line, and they lie therefore near the northern boundary of Nevada. A couple of miles eastward is a small active hot spring (No. 15 to be described) and within 30 miles to the north are several rather large active ones.

As is commonly the case, the deposits here are strongly tinged with ochre yellow with occasional pure white masses interspersed. They are mound-like with gradually or steeply sloping sides practically devoid of the sage brush vegetation which covers the surrounding area. Similarly colored, dome shaped or conical mounds are also

numerous in Lassen National Park, California, but here they are in a very mountainous region and are sometimes built up on steep slopes. Such deposits are almost always uniformly of a soft calcareous nature and must weather very rapidly.

The harder deposits of siliceous sinter laid down by alkaline hot springs weather more slowly, but are less conspicuous as they assume a dull gray tinge. A most remarkable series of these is to be seen west of Pyramid Lake, Nevada, representing the remains of a group of hot springs and geysers many miles in extent. Pyramid Lake derives its name from an enormous sinter cone, which rises out of the bosom of the lake and along the western shore are others of great size, entirely extinct, but still retaining the characteristic structure of geysers or boiling springs (Plate 2, fig. 1) especially where the interior cavity may still be seen. To the westward are many other groups and the road passes for several miles over the rough weathered surface of a shelf which formed part of a vast hot spring terrace. The springs in this region are entirely extinct, but some miles beyond them to the west are some active springs at Ameede, California (Hot Spring No. 9).

References to other groups or series of extinct springs might be added at great length for the present active ones are but scattered remnants of a vast and gigantic series which once dotted this entire region. Most stupendous of all is the well known Bryce Canyon in southern Utah, apparently eroded from the deposits of an extinct hot spring many miles in extent. The writer has given elsewhere his reasons for believing that Bryce Canyon originated in this way.

The following list which includes 34 hot springs or groups of springs is arranged in the order in which we visited them. The arrangement is therefore one of convenience only as it does not coincide with any grouping which might be made on the basis of composition, temperature or otherwise. Also it does not include some springs visited where we failed to obtain collections, due usually to the springs having been walled in, piped for drinking water or otherwise despoiled.

List of Hot Springs

No. 1. Hot Springs, New Mexico. The springs are near the town at the foot of a small hill. Some have been turned into baths, but there is a small amount of seepage forming small pools in a large marshy meadow. Some of these pools are barely tepid, but a flowing stream which forms the overflow from several small springs near the upper edge of the marsh, traverses the marsh for a distance of several hundred yards. The temperature of this stream, which is several

feet wide, is not very high, in the neighborhood of 40° along most of its course. The specific gravity, corrected for temperature is 1.0039 and pH 8.1. It supports a fauna of snails, chironomid larvæ, and fish. About 60 miles south of this locality is another hot spring known as Radium Hot Spring emitting water at 85°, but this is piped to a bath house from the rocky hill side and affords no opportunity for biological collecting.

No. 2. Hot Springs Station, Nevada. This is 5.8 miles north of Beatty, on the railroad and about a quarter of a mile off the highway leading to Goldfield. The springs, which have a temperature of 40.4°, are led into a bath house and into a cement pool containing green algæ. They flow from the lower edge of a low ridge and there is in a marsh below a small pond in which the water is cool. The spring water has a specific gravity of 1.0016 and pH of 7.2. In the neighborhood there are other places where water oozes through the desert floor and supports patches of vegetation but no other warm springs were noted.

No. 3. Goldfield, Nevada. This is about 12 miles from Goldfield on the road which leads to the mining town of Weepah. It is led into a large swimming pool, but there is a considerable overflow of hot water from the spring which forms a stream several feet in width that flows out into the semi-desert plain. The water has a temperature about 40° at the head of the stream which drops to 35° within about 50 yards. This stream flows in a ditch near the spring, but spreads out below where it is lined with bullrushes. The water contains a considerable amount of algal growth and insect life.

No. 4. Silver Peak, Nevada. This is about 50 miles west of Goldfield and about the same distance east of the California state line. The springs are at the western edge of a large alkali flat several miles in length which is dry during most of the year, but was then covered with water from rains that had preceded our visit. The country to the north is mountainous and the hot springs are at the lower edge of the steep rocky slope, only a few feet above the flat or marsh which is really a salt desert when dry, or a vast shallow lake when covered with water, from the center of which rises a conspicuous dark rocky hill. There are a number of small springs and below them the soil is wet, spongy and covered with a coarse growth of grass (*Distichlis spicata*). The individual springs vary greatly in temperature; some are extremely hot (67°; 53.5°) while others are quite cool and in one case two very hot ones only six feet apart had between them a cool one. The specific gravity of the water is high, 1.0212 with a pH of 8.3. The animal life in the springs includes larvæ of

mosquitoes, Ephydra and Stratiomyia, as well as some water-bugs and the annelid, Tubifex. Nearby is a large cold spring, impounded for use in an ore-crushing mill.

No. 5. Whitmore springs, near Convict Lake, California. These are reached by a road which leaves the highway between Bishop and Mono Lake about 38 miles north of Bishop. The side road leaves the north and south highway at a right angle and the springs lie about three miles to the east over a very winding and little used road. Before reaching the springs one passes along the southern slope of a small open grassy valley through which a stream flows eastward. Waring ('15) describes two large springs of low temperature (maximum 37.7°) arising in a meadow near this point. We did not visit these, but noticed them from the road lying below and to the north where they water the pasture land. The springs to be described are in the Inyo National forest although the immediate vicinity is practically treeless. They consist of a number of boiling hot and warm pools which line the southern bank of the stream and lie quite near to the edge of a steep slope which rises about fifty feet above the stream. This slope is composed of hot springs deposits, showing that the extent of the springs has been much greater in the past. In addition to the pools there is one very small geyser which erupts a small amount of water to a height of several feet. The creek is decidedly warm but only a very small amount of water flows into it from the springs along the bank. The specific gravity of the water in the springs is about 1.0012 and the hydrogen-ion concentration 8.5 where most of our material was collected but mosquito larvæ were taken from one more alkaline pool, having a pH of 8.8. These springs are in a very attractive setting between the steep slopes on each side of the stream and, looking up the valley to the westward, the high Sierras are visible in the distance.

A few miles further north next to the main highway are the Casa Diablo Hot Springs. These are not extensive and are apparently rapidly disappearing. They are located on the slopes of a hillside just above the road and the only one which seems to be actually flowing has been boxed in to form a tiny bath house. The rapid decrease in flow of these springs is said to date from the earthquake of 1915. Waring ('15) found in 1908 several springs discharging water, but only one is now actually flowing. He also states that some fifty years previously another spring nearby, now dry, was active.

No. 6. Fales Hot Springs. These are located about 14 miles northwest of Bridgeport, California, close to the main highway between

that town and Carson City. One which has a temperature of 67.8° is confined in a large concrete pool, and over the other which is of much lower temperature has been built a bath house. The overflow from both springs is combined and flows as a small stream to the northwest through a gully. Considerable quantities of gas probably carbon dioxide, bubble through the pools and the pH of the overflow is rather low, 7.5, while the specific gravity of the water is rather high, 1.0030. The stream supports a considerable growth of filamentous algæ and flows over a number of small terraces or cascades which it has deposited. Waring ('15) gives Fahr. 60.5° C. as the highest temperature, but it is now much higher, due perhaps to the cementing of the pool, although the difference is considerable. There are extensive deposits, above the present springs indicating that they were much more extensive in the past.

No. 7. Walley Hot Springs. These are several miles west of Minden, Nevada and about 15 miles south of Carson City. They are not on the main highway between these two places, but are reached by traveling westward from Minden to the old Pony Post road and proceeding northward on this road for about a mile toward Carson City. At this point the road follows along the edge of some foothills of the Sierras which rise to the westward. The springs are directly east of the road while beyond them toward Minden stretches out a vast marsh which supports a heavy growth of tall rushes. The springs are all small, scattered along the marsh which is separated from them by open water at least several feet in depth and twenty or thirty feet in width. Into the marsh there also extends an arm of open water with a slight but noticeable flow, indicating a much greater flow of water than that which comes from the springs above the water's edge. In the water which is warm (36°–37°) a number of large fish and ducks ventured out on the open water several times during our visit. The water appears quite clear and is practically fresh as we could detect no salts in solution by means of our hydrometer. The pH, is however, comparatively high, 9.6 or over. The temperature of the pools varies greatly and some are far too hot to support animal life. This one of the most extensive springs which we visited and undoubtedly all the water in the marsh comes from these and associated springs, some of the larger ones doubtless below the level of the water in the swamp. These springs (Plate 2, below) are in their natural condition, but about a quarter of a mile further north is another group similarly located which form the basis of water cure and mud bath for arthritics.

No. 8. Steamboat Springs, Nevada. These lie directly to the

west and above the main highway between Carson City, Nevada and Reno, about 20 miles north of the former, and one mile north of Steamboat Springs Station. They form the remnants of what have been much larger springs in the past and emerge from an extensive sinter deposit about five hundred yards in length extending north and south, with a width of perhaps about three hundred yards. The highest part of the ridge which is parallel to the road is about sixty or seventy feet in height and composed of porous siliceous sinter. There are several narrow fissures within which the boiling of water may be heard, but in only one place is there an overflow that forms a small stream a foot or two in width which flows over the sinter for a hundred yards or more. Along its course there is a good deal of vegetation and at spots the water spreads out to form flat marshy areas a few feet in diameter. Toward the northern end of the sinter deposit the ground is hot in places and sounds hollow to the tread. These springs were visited in 1870 and are described by Hague and Emmons ('77, p. 825). It would appear that the springs were more active at that time, giving forth a much greater volume of water, but this may not be true as some hot water is now piped to a settlement below and one bored well at the northern end was spouting boiling water to a height of about 25 or 30 feet at the time of our visit. Near this are a few small pools and sinter cones which appear to be drying up as a result of the new well.

No. 9. Amedee, California. This is a group of several very hot springs, one of which is boiling at a temperature of 95.6°. They are near the southeastern border of Honey Lake, close to the highway between Pyramid Lake, Nevada and Susanville, California. One group of springs supplies some bathhouses and furnishes hot water for a hotel, but two are still in more or less natural condition and the water from these is led off in ditches for irrigation purposes. One of these is boiling and the other forms a small series ranging from 40°–50° in temperature. The specific gravity of the water in the run-off from these springs where collecting was done is 1.0012 and the pH 8.5. According to Waring the water contains a considerable amount of sodium sulphate and some silica. The latter is sufficient in amount to cause the silicification of wood which has fallen into the spring. There is but little tufa in the neighborhood of these springs, but further northward and west above the northern border of the lake at Shaffer there is a considerable amount which forms one series of crags fully 50 feet high. These are similar to the very large and extensive tufa formations which characterize the country further east near Pyramid Lake. South of these crags is a series of hot springs,

said to be rapidly decreasing in size and next to them is an overgrown swampy pool of cool water overgrown by coarse vegetation.

Lassen National Park. Springs Nos. 10–14 are located in Lassen National Park which contains many thermal springs of varied types, including a hot lake, hot and boiling pools, steam vents, boiling mud-pots and some small actively boiling, almost geyser-like vents which emit steam and water. There are, however, no true geysers. The hot springs of the Park, are confined mainly to three areas. One of these is in the southeastern part of the park, about two miles south by southwest of Lassen Peak in a straight line and southwest of Lake

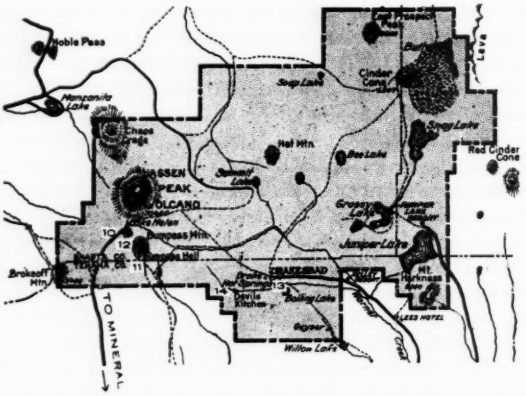

FIGURE 2. Map showing location of the hot springs in Lassen National Park, California which are referred to in the text. (Slightly modified from one issued by the National Parks Service.)

Helen. It includes only small springs which are located mainly along the slopes of ravines, but biologically these are very interesting. Springs No. 10 and 12 are located here. A second group, much larger, more spectacular and extremely varied in character, lies almost directly south of Lassen Peak at a distance of two and one half miles. This group, known as Bumpass Hell, lies on the ancient crater rim of Lassen Peak at an elevation of 8,000 feet where it occupies a sloping area of some 80 acres bordered to the north and west, and partly on the other sides, by a ridge which rises above it. This locality is designated as spring no. 11. The third area lies near the southern boundary of the park. It extends over a large area, from five to eight

miles southeast of Lassen Peak in a straight line. Here the elevation is much lower, varying from 5600 to 5900 feet.

No. 10. This is along the trail which leads to Lake Helen about two miles (by trail) below the lake. This trail leaves the road which enters the park from Mineral, about eleven miles from the latter place. At this point there are a number of small pools that water a grassy slope. The temperature of the water varies from 38°–47° where collecting was done and the pH varies from 6.7–7.3, with a specific gravity of 1.0014. These springs are well above the road and before reaching them one passes many mounds and slopes formed by deposits from springs not now active. These are in part pure white, but are mainly ochre yellow, with very little admixture of red.

No. 11. Bumpass Hell. Although this remarkable area exhibits a great variety of thermal phenomena, the springs containing animal life are not numerous. The ground about the springs is in considerable part bare, but a few of the springs contain algæ and there are grasses surrounding others. The water has a specific gravity of about 1.0016 and a rather low pH of 5.7–6.5, varying apparently with the content of hydrogen sulphide. Many of the pools are turbid with clay or sulphur in suspension while others are far too hot to support animal life. Bumpass Hell is difficult to reach as the approach from the west road involves a stiff climb, descent into a valley and another steep ascent to the springs.

No. 12. This is quite near to no. 10, in a small ravine next to a rushing brook not far above the road which leads into the park from Mineral. It is one of a considerable number, but the only one in which material was collected. The specific gravity was not determined, but the pH is unusually low, 5.1.

No. 13. Drakesbad, Lassen National Park. This is a small cemented pool about half a mile west of the hotel. The water is scarcely warm, 28.2°, specific gravity 1.0021, pH 6.7, but is interesting as the only water striders collected were obtained here.

No. 14. Devil's Kitchen, Drakesbad, Lassen National Park (See Plate 4). This is an area, several miles west of Drakesbad, quite similar to Bumpass Hell, but of lesser magnitude and at a lower elevation. In spite of the varied character it was biologically unproductive. Several miles southeast of Drakesbad is Lake Tartarus, a large "boiling" lake about four hundred feet in width. The water is very turbid with clay in suspension and the shores are so muddy that there appears to be no animal life present.

No. 15. 25 miles southwest of Denio, Oregon. This spring lies in

the northern, almost uninhabited section of Nevada close to the Oregon border. It is six miles off the road from Cedarville, California, about 76 miles from the latter place. The spring is small but emits a considerable volume of clear water with a specific gravity of 1.0000 and pH of 8.4. The temperature is 32.5° in the overflow where our collecting was done. Although small, this spring is biologically very interesting. It is in an area which has been at one time thermally very active. There is much silicified wood a few miles to the southeast in a hill where opals are mined and to the west, near the main road there are the remains of other hot springs present as large, much weathered mounds of calcareous deposits formed by the action of large springs now entirely extinct.

No. 16. Six and one-half miles south of Denio, Oregon. At this place there are several small springs in a group near the highway to Cedarville, California. They are in flat grassy meadow about half a mile east of the mountains which rise abruptly from the desert. The green area extends eastward and a large pool with water near the boiling point (spring no. 16[a]) is located about a quarter of a mile east of the first group. There is practically no deposit except a small amount of clayey mud formed at the margin of these springs and even the large one, which produces a considerable amount of water that is led off for irrigating the meadow, is scarcely raised above the surrounding plain. The water has a specific gravity of 1.0015 and pH 8.5. There is plenty of ground water in the meadow, probably originating from springs, and to the southward at a distance of about two miles is a large pond or lake fed by the Thousand Creeks. These springs are a very interesting group.

No. 17. Twenty-one miles southeast of Denio, Oregon. Like the last, this locality is in northern Nevada, on the valley road to Winnemucca, Nevada which lies 83 miles further on to the south. The main spring arises in a mass of pink chalcedony a few feet in height and below in a depression there is some slowly flowing hot water which forms a sinuous elongate pool bordered by sedges and grasses. Here in water at a temperature of 32°–40° a number of beetles were obtained. The water is practically free from dissolved salts with a specific gravity of 1.0001 and a high pH of 9.4. The country in the neighborhood of the three springs (nos. 15, 16 and 17) near Denio has been very interestingly described by Reeds ('27) who refers to many geological features of the region. About the rocks at this spring we noted a considerable number of cast snake skins. Evidently the warmth from the water is attractive to snakes (See Plate 4).

No. 18. Golconda, Nevada. These springs are close to the small

town which is some 18 miles east of Winnemucca on the transcontinental highway. There is a hotel built at some of these, but a short distance away are several good sized pools at the head of a large open meadow. They set on low mounds of sinter which rise only a few feet above the surrounding surface and support a good growth of grass. Some are too hot for animal life, but one contains water at 50° and below while in the overflow the water is cooler. The water is nearly fresh, specific gravity 1.0008 and pH 8.1.

No. 19. Paradise, Nevada. This may be reached either from Golconda or Winnemucca; about 60 miles from the former and 40 from the latter over none too good roads. It is visible from the road about a quarter of a mile to the south, close to the Humboldt River and north of Hot Springs Peak. The spring arises from an old sinter cone or conical mound about 20 feet high. The water no longer flows over the top as the spring has been tapped for irrigation and led through a ditch toward a ranch house. The sides of the ditch are muddy, with abundant grass, and a great variety of water beetles were obtained here where the water cooled somewhat. The specific gravity is 1.0012 and pH 7.6 (See Plate 5).

No. 20. Twenty-nine miles south of Winnemucca, Nevada. These are in the broad valley between the Payute range and the Havalla mountains, reached by a passable but indescribably rough road from Winnemucca. The springs are on the gentle slope of a low hill beyond the foothills on the eastern edge of the valley. There are about 25 pools, the largest 10 or 12 feet in diameter set in white travertine sinter which forms a gradually sloping face. There are many marshy spots and there is a good carpet of grasses over these. Some pools are bubbling and near the boiling point, and furnish a considerable flow of water that is carried out into the valley for irrigation. The entire area occupies several acres, and is several times longer (in a north and south direction) than wide. These springs were described in Hague and Emmons' report ('77, p. 687) as they existed in 1870 and their description indicates that there has been but little change in the springs during the intervening period of nearly 60 years. The specific gravity of the water is 1.0014 and the pH 8.4–8.7. An analysis given in the publication cited above indicate that the main mineral content is calcium carbonate (See Plate 6).

No. 21. Sou Hot Springs. These were described in the report just cited. They lie to the south of those just mentioned, 72 miles from Winnemucca and are reached over a continuation of the same road. They lie toward the western edge of the desert valley on a low mound of travertine which slopes gently from the flat plain to a height of

60 or 70 feet. This is surmounted by a series of several warm pools scattered over the more or less level top about an acre in extent. The largest of these pools is about 25 feet in diameter and the larger ones are surrounded by tall sedges, grasses and other vegetation; some much smaller ones are hot or boiling. In addition there are a number of pits which are no longer filled with water. Much of the water from this group of springs has been diverted by blasting in an attempt to irrigate a small ranch on the desert about a mile further south and this is no doubt the reason that the springs appear to be much less active than they were in 1870. At that time as described and beautifully illustrated in Hague's account (*loc. cit.*) the water level reached the rim of the pools. The specific gravity of the water is 1.0020 and the pH 8.0. According to Hague the principal material in solution is sodium sulphate, with very little sodium chloride, although the Osobb Valley which lies directly south is a salt desert and there are strong brine springs near by, which according to Hague are also warm (125° Fahr.), but we did not have opportunity to search for these. Evidently the source of the water in the Sou springs is not derived from the seepage of meteoric water through the salt fields. Although this valley has been known as the Osobb Valley it is known to ranchmen locally only as the Dixie Valley. One of the pools in this group is shown on plate 3.

No. 22. Twenty-six miles south of the town of Battle Mountain, Nevada. This is on the eastern side of the Reese river valley on the main highway from that place to Austin, Nevada. The springs arise as two very shallow pools only a few feet in diameter with muddy bottoms and surrounded by level, soft, damp soil. They are on the slope of a low hill which encroaches on the valley as an extension of the foot-hills of the mountain range that lies to the eastward. There is a very scant overflow, but the vicinity of the springs is indicated by a noticeable amount of green grass which contrasts with the drab coloring of the surrounding desert flora. The water is nowhere very hot, but ranges in the neighborhood of 40° in the pools. The specific gravity of the water is 1.0014 and pH 7.8.

No. 23. Watt's Ranch, 37 miles south of Battle Mountain, Nevada. This group of springs is near the same road as the last, about eleven miles further south. These springs have been described by Hague ('77, p. 633) and his description of the locality leaves no doubt of their identity. However, the position and temperatures of the springs do not agree and I hesitate to make comparisons of their condition at the two dates.

It seems probable however that there have been quite considerable

changes in position and an increase in the temperature of the water in some springs since 1870. One spring which is nearest the road formerly arose from a sinter deposit about eight feet high which has been cut through to lead water into the ranch house. As a result this spring is drained to the level of the opening and is not flowing perceptibly; it is not distinctly warm.

Over an area of several acres to the westward of this are a number of hot pools which flow slightly over a flat meadow covered with grass. The pools are lined with soft gray mud, but the water is quite clear unless disturbed. Various beetles, crustaceans and dragon-fly nymphs were obtained here. The water is but slightly impregnated with salts, and has a specific gravity of 1.0008 and pH of 8.0. According to an analysis given by Hague the pasty gray material deposited in these springs contains a considerable amount of silica as well as calcium carbonate.

No. 23[a]. About six-tenths of a mile north of the group just mentioned is a large spring which gives off a strong flow of hot water that is led off through a ditch for irrigation. This spring is on the side of a low hill that rises above the plain on all sides. After flowing for about 100 feet the water is sufficiently cool to support animal life and here a succession of small cascades and pools afforded an opportunity to collect a number of insects and a species of planarian. The water is more saline than that of the nearby springs to the south, with a specific gravity of 1.0021 and also slightly more alkaline with a pH of 8.5 (See Plates 3 and 6).

No. 24. Beowawe, Nevada. These springs are about seven miles south of the town of Beowawe which is reached by a road that leaves the main transcontinental highway (Victory highway or U. S. 40) at the small railway station of Dunphy, 56 miles west of Elko, Nevada. The springs, together with a number of geysers, some of which erupt at frequent intervals to a height of 15 or 20 feet, occupy a shelf of siliceous sinter about half a mile in length on the western slope of the mountain that borders the eastern edge of the valley southwest of Beowawe. The sinter deposit rises at a steep slope to a height of about 200 feet and its upper nearly level face extends in places to a width of over forty feet. The overflow from the geysers and from a number of hot springs flows down the side of the sinter at several places and below in a meadow close to the edge of the sinter escarpment is a large very hot pool which is said to erupt at times. The specific gravity of the water is 1.0063 and the pH 9.6 or over. A number of beetles and chironomid larvæ were taken in the overflow from the upper springs and geysers. These springs are most remark-

able for their large extent, very large sinter deposits and the presence of large, true geysers. This group was well described by Peale ('83, p. 322), as Volcano Springs but has apparently entirely escaped attention since that time. Outside of Yellowstone Park, they appear to be the only true geysers of any considerable size in the United States (See Plate 5).

No. 25. Near Deeth, Nevada. These springs are 20 miles north of the town of Deeth, 15 of which are over the road to Charleston, Nevada, but the last five must be made over an abandoned road which leaves the main road just after passing two conspicuous small buttes on the right. This spring has built up a dome or flattened cone about fifty feet in height of grayish travertine, but the water no longer flows over the top as it now escapes through a crevice some forty feet below the rim, whence the water spreads out over the nearly level ground at the base to form a very shallow pool. The edges of this are margined by a rim of travertine beyond which the water plunges over a travertine cascade to the southward into a small gulley some thirty feet in depth. The water has a low specific gravity of 1.0008 and pH of 7.4. This spring is evidently diminishing in activity.

No. 26. Near Wells, Nevada. This is reached from Wells over the road to Metropolis. It is four miles from Wells on the right hand side of the highway. Set in the flat plain at the lower edge of a steep hill of rough rhyolite, topped with tufa, is a small pool of warm water (32°–36°). The pool is surrounded by a growth of grass (Distichlis) and rushes where the water seeps into the soft muddy soil. The specific gravity of the water is 1.0018 and pH 7.9.

No. 26^a. This arises just a few feet above Spring no. 26, but issues from the rocky hillside and is quite different in composition, with a specific gravity of 1.0015, a strong odor of hydrogen sulphide, pH of 6.9, and the water contains strings of sulphur bacteria. Its temperature is about that of the other spring (33°), but the water has been led away from the pool below by means of a wooden trough.

No. 27. On returning to Wells this spring was noticed by my daughter on the south side of the highway. It is about two and one-half miles from Wells. The spring flows a considerable amount of clear hot water which runs down a natural gulley, nearly parallel with the road, to the westward, and is entirely in its original condition. It contains some filamentous green algæ and where the water has cooled to about 40° a number of insects were secured. The specific gravity of the water is 1.0017, pH 7.1 and no odor of hydrogen sulphide is noticeable.

No. 28. Ruby Valley, 65 miles south of Wells, Nevada. This large group of springs may be reached from Wells over the Valley road which leads from Wells to Eureka along the valley east of the high Ruby mountains. By road it is 65 miles from Wells. The springs are in the nearly level valley about half a mile east of the road on a low rounding knoll covered with white sinter. Although actively depositing a hard sinter, they have built up no cones, but lie close to the level of the plain. They occupy an area of three or four acres and vary greatly in size and temperature. Some are boiling and a considerable amount of gas rises in bubbles from a few. Some are shallow with muddy bottoms, while others have deep funnels in which the water is of a clear blue color. The muddy pools are not so hot and some range about 40° or lower. There is a considerable flow of water from the group, which includes perhaps thirty or forty separate springs varying in size from pools 20 feet in diameter to ones of very small dimensions. On account of the large extent and diversity of this group, it supports a large fauna and much grass, most of which is cropped by a herd of cattle which are pastured in the vicinity. The water has a specific gravity of 1.0009 and is noticeably alkaline with a pH of 9.4.

No. 29. Wendover, Utah. Directly south of the town of Wendover which is close to the Nevada-Utah state line there arises from the base of a low, rocky bluff, near the western edge of the Great Salt desert, a group of large warm springs with a temperature of 27°–28°. These supply several large ponds which are surrounded by a growth of grass and rushes. Mosquitoes breed here in supreme abundance and biting flies of the genera Tabanus and Chrysops are also abundant. The water is saline, with a specific gravity of 1.0041, but much less so than would be expected if derived from meteoric water anywhere in the vicinity as the desert is covered with crystalline salt which goes into solution when rain falls. The flow from these springs is evidently very large and their source must be through a deep fault.

No. 30. Grantsville, Utah. These are between the main highway and the southern shore of Great Salt Lake, 4.7 miles west of Grantsville which is not far west of Salt Lake City. These are only warm with a temperature of 30°, a specific gravity of 1.0207 and pH of 7.7.

No. 31. Hot Springs Station, Utah. These springs are about ten miles north of Ogden, Utah and close to the railroad station of Hot Springs. They form a small group, one of which is at the boiling temperature while the others are extremely hot. A large flow of water issues from these, some of which had been led to a bath house that burned down at some time before our visit. The water is highly

saline, and deposits a large amount of ferruginous material which stains the ditches and surrounding soil where the water is led off to an extensive flat below the springs. No material was obtained here, but about a quarter of a mile further south is a much smaller spring, utilized for baths. In the overflow with a temperature of about 35°, specific gravity of 1.0146 and pH of 8.2, a number of insects and an amphipod crustacean were collected.

No. 32. Ogden Canyon, Utah. This issues from the southern wall of the canyon at its lower end where the road crosses the stream, about 3 miles from Ogden, Utah. The water flows in considerable quantity and finds its way over the rocky slope to the stream some forty feet below. The water is very hot at its source and produces a thin layer of highly ferruginous deposit. It is quite saline, with a specific gravity of 1.0063 and pH of 8.3.

No. 33. Midway, Utah. These may be reached from Provo, Utah over the road which ascends the Prova Canyon northeastward to the town of Midway which is about 25 miles from Provo at an altitude of 5500 feet. Near the town are several groups of hot springs known locally as "hot pots" as they have formed large deposits of sinter and each spring is set in a conical mound. Just northwest of the town over an acre or two there is a group of half a dozen of these mounds rising ten or twenty feet above a rounded hill covered with whitish sinter. The openings vary from ten to twenty feet in diameter, but the water lies eight or ten feet below the contracted orifice. The water was out of reach, but is evidently cool or scarcely warm, although a small amount of gas bubbles up from the depths. These springs are evidently rapidly decreasing in activity and we were told that one small dome in the yard of a house, where the water level is now several feet below the rim, had been flowing over the top fifty or sixty years ago. Nearer the town is a large conical mound at least fifty feet high with an opening some twelve feet in diameter. The water is now forty feet below, but this spring has been tapped near the base to supply water for a hotel and natatorium. The water in this crater is boiling. Northeast of the town is another group on a small sinter hillside, with a very small amount of overflowing water and on the verge of extinction. The water of these springs has a specific gravity of 1.0021 and pH of 7.4. There is no ferruginous color to the deposits.

No. 34. Monroe, Utah. These springs are directly east of the town of Monroe, at a distance of about half a mile. They issue from the western slope of a hill at the base of the high mountains that rise from the eastern edge of the narrow valley in which the town sets.

The amount of flow from these springs is not very great but they supply a natatorium after flowing down the steep slope. The water has a specific gravity of 1.0024 and pH of 9.0. No very considerable amount of deposit is produced but that which appears is of a bright ferruginous color characteristic of all the springs (Nos. 31, 32 and 34) which we visited east and south of Great Salt Lake with the exception of no. 33 at Midway which lies to the east of the Wasatch Mountains.

There are a few observations contained in the preceding account which are of geological rather than biological interest, but as certain of the phenomena exhibited by hot springs are open to more than one physical explanation, it seems worth while to call attention to some of the facts observed by us. During the year 1924 there appeared in the Journal of Geology a number of papers on hot springs which include a very full and illuminating account of the nature, origin, source of heat, temperatures and distribution of hot springs (Day and Allen '24; Adams '24; Van Orstrand '24; Meinzer '24 and Sosman '24[a], 24[b]).

Two sources of water are possible in the case of hot springs. Juvenile or magmatic water arising as steam from very great depths where it is given off by underlying magmas is a probable source in many cases and Meinzer (*loc. cit.*) believes that the thermal springs of Nevada and Utah derive their water mainly from this source. His reasons are that the springs are generally associated with faults, that they do not regularly occur closely related to volcanic rocks from which they may derive their heat, and that they cannot generally be attributed to artesian structure. The last mentioned factor is necessary if the hot water be derived from meteoric or surface water which must descend so as to come into contact with heated rocks. This second source of water is available without artesian structure before emergence as a spring in some localities, such as Lassen Park where the springs are below the source of surface water and snow and there Day and Allen ('24) believe that meteoric water supplies the springs which are very close to subterranean sources of heat in the mountain which is an active volcano. Our own observations in Lassen Park lead us to a similar conclusion.

Several observations of our own tend to confirm Meinzer's view of the magmatic origin of the waters of a number of the springs which we visited in Nevada and Utah. At Silver Peak, Nevada (Hot Spring no. 4) there are a number of hot springs and some cold ones interspersed, within a few feet of one another. In this case the cold springs arise from the mountain adjacent and the hot ones must certainly be attributed to an entirely different source. In an earlier

paper ('17, p. 89) Meinzer refers to a case in the Darrough hot spring group in the Big Smoky Valley, Nevada in this region where a small spring with a temperature of 61° Fahr. arises within 100 feet of a hot spring having a temperature of 198° Fahr., indicating an entirely different source. Another evident case where it seems impossible to attribute the source of warm springs to surface or artesian water is at Wendover, Utah (Hot Spring no. 29) on the western edge of the Great Salt Desert. Here, as I have noted on another page, a surface origin seems to be precluded, but as the low temperature of these springs suggests an artesian origin, no simple theory seems to account for them.

The general belief concerning the age of the springs in the region visited is that they originated before the close of the Tertiary and that they are not now, nor have they in comparatively recent times decreased in volume. After visiting a number of these springs and traveling over the intervening territory it seems quite evident that the thermal activity of the springs is markedly on the wane. As already related there are evidences of extinct hot springs in many localities. Some of these give little indication of extensive erosion and are clearly quite recently extinct, while others remain only as mounds or masses of deposits, most certainly the products of hot-spring activity. In some cases the deposits of tufa from non-thermal sources, *e.g.*, in the vicinity of Pyramid Lake, derived from the evaporation of the former Lake Lahontan, simulate the deposits of hot springs. In this region, however, there is evidence that some of this material has been produced in hot springs of which there are remains within a very short distance of the Pyramid Lake hotel (Plate 2, fig. 1). Along the shore further northward there is also a well preserved structure which is surely the remains of a geyser, with the inner cavity still partially intact. These must certainly be of comparatively recent age as they are not far above the present level of the lake. At other localities it appears that certain hot springs now active (Nos. 6, 8, 9, 33 and the Casa Diablo hot springs mentioned under no. 5) have either decreased in activity within recent years, or give good structural evidence of reduced flow of water, or show clearly that they were formerly more extensive. At places where springs have been damaged or diverted for irrigation or other purposes, it is difficult to determine the effect which must be attributed to such changes, but taken together the evidence indicates without question in my mind that the flow of thermal water in this region is quite consistently diminishing.

In the detailed account which follows, I have included references

to the zoological material which we collected in the several hot springs just described and have added certain other records which have been published by others in connection with the fauna of thermal springs of other regions. The fauna of the springs in the areas which visited had never been examined previously so that published references to them contain almost no zoological data. As will be seen, I have also discussed various other matters with reference to the distribution, adaptations and temperature relations of particular groups of animals where these have a bearing on the thermal fauna. Much of the previously published data relating to animal life in thermal springs is reviewed in my previous paper (Brues '24) and I have avoided a repetition of the references and discussion presented there.

PROTOZOA

If we compare the reactions of bacteria in relation to high temperatures (see p. 206) with those of the Protozoa among animals, the great breach which separates these two series of unicellular organisms is at once apparent. Unfortunately no data are available for the fauna of American hot springs, but Issel ('06) has reported the occurrence of a number of Protozoa in Italian thermal waters. His list includes fifteen species and is reproduced below with some changes in arrangement and nomenclature.

SARCODINA

ACTINOPODA

Actinophrys sol Ehrb. 38°.

RHIZOPODA

Amœbidæ

Amœba proteus Ehrb. 35°–45°.
Hyalodiscus limax Duj. 35°–45°.

INFUSORIA

CILIATA

Enchelynidæ

Enchelys sp. 42°–43°.

Chlamydodontidæ

Nassula elegans Ehrb. 42°–48°.
Chilodon cucullus Müll 35°–39°.

Chiliferidæ

Loxocephalus granulosus Kent 36°.
Frontonia acuminata Ehrb. 40°–50°.
Colpoda cucullus Müll 35°–39°.

Pleuronemidæ

Cyclidium glaucoma Müll 41°–51°.

Paramoeciidæ

Paramœcium aurelia Müll 38°–40°.

Plagiotomidæ

Metopus sigmoides Clap. and Lachm. 35°–45°.

Pleurotrichidæ

Oxytricha fallax Stein 32°–45°.

Euplotidæ

Euplotes patella Ehrb. 32°–35°.
Cothurniopsis imberbis Ehrb. 35°.

It will be seen that the range of none of the species exceeds 50°, with the single exception of *Cyclidium glaucoma* which he found at temperatures of 41°–51°. This is fully in accordance with the maximum temperatures observed for various forms of invertebrates. In an earlier ('01) paper Issel reported a temperature of 54.5° for protozoa but this is not repeated except as a reference in 1906. Still later ('10) he has reported *Amœba limax* at 52°, which would increase the upper thermal limit for Protozoa one degree. Some much earlier observations of Ehrenberg ('58) relating to a number of Protozoa in thermal water in Ischia offer no further data since only the extreme temperature (81°) of the spring is recorded.

For comparison with these freee-living types there are available some very recent data on the thermal resistance of certain forms parasitic in warm blooded animals. Boeck ('21) has determined experimentally the thermal death point of a number of Protozoa which occur as intestinal parasites of man. His data relate only to the resistance of the cysts which are able to withstand much higher temperatures than the active stages of the same animals. These lethal temperatures range from 64° C. to 72° C., or 147°–169° F. and thus extend well to the upper limit of tolerance of chlorophyll bearing algæ as observed by Davis ('97), Miss Tilden ('98), Setchell ('03) and myself (Brues '24) in Yellowstone Park. This would show that the encystment of Protozoa causes them to acquire a resistance to heat comparable to that noted in the spores of bacteria when compared to the vegetative forms.[1]

Boeck's observations relate to six different forms, including both Rhizopoda and Mastigophora and the lethal temperatures as determined are as follows: *Entamœba histolytica*, 68°; *E. coli*, 76°;

[1] More recent researches cast doubt upon the accuracy of these data, as I have indicated in the postscript to the present paper (p. 228).

Iodamœba bütschlii, 64°; *Giardia intestinalis*, 64°; and *Chilomastix mesnili*, 72°. Relating to these species one other matter is of considerable interest, namely, that the greatest divergence noted is not between unrelated forms but among rather closely similar species. Thus the two species of Entamœba and the Iodamœba include among themselves the entire range of temperatures recorded for the whole series (64°–76°).

The existence of such conditions among Protozoa completely breaks down any distinction drawn between animals and plants on the basis of their resistance to high temperatures. If we attempt to explain these lethal temperatures on a physical basis, it is possible to regard them as associated with a loss of water which increases the coagulation point of albumin-like proteins within the cells. This is the explanation offered by bacteriologists with reference to the greater heat resistance of the spores of bacteria when compared with their vegetative stages. On the basis of the coagulation point of albumin we should expect that the protoplasm of the protozoan spores had its moisture content reduced to about one-fourth that of the growing organism. Whether this is actually the case it is no more possible to determine accurately in the case of Protozoa than with bacteria, although in the latter Cramer ('91) and Benecke ('12) have given evidence to show that the protoplasm of spores is actually in a state of partial dehydration. Up to the present time the only plausible explanation of these phenomena seems to be the one just outlined. It can hardly be applicable to the growing stages of bacteria, developing in water or any other liquid medium, however. Under these conditions the requisite exsiccation could not come about, especially in the case of algæ developing at high temperatures. In the case of animal life developing at 50° or thereabouts the amount of desication necessary would be slight and by no means in excess of that compatible with complete metabolic activity. That exsiccation may proceed well beyond this point without ill effects has been well established.

Delicate adjustment of certain flagellate Protozoa to high temperatures is shown by some recent work of Cleveland ('28) on Tritrichomonas. A type of these organisms derived from frogs (*T. angusta*) grows well in culture at room temperatures, but fails to grow at all at 36°, while another type (*T. fecalis*) derived from the alimentary canal of a human subject was found to develop readily at 36° and to grow even at 37°. Associated with this difference in respect to high temperatures is a morphological difference between the two. *T. angusta* is characterized by the presence of granules in

the axostyle while these are lacking in *T. fecalis*. It seems therefore that unless the difference may be due to acclimatization in a homœothermic animal, that the heat-sensitive part of the animal may be the granules in the axostyle.

CŒLENTERATA

The members of this phylum are of course almost entirely marine, and among the few fresh-water types like Hydra which have an opportunity to migrate into hot springs, none appear to have done so. Among the marine cœlenterates the corals are notable on account of their restriction to the warmer seas and their relation to high temperatures of the medium in which they live is therefore of interest in connection with the thermal environment. Fortunately there are available in the literature some observations and experimental data relating to this phase of their biology.

Mayer ('17) obtained some comparative data on the temperatures fatal to a number of species of corals and reached the conclusion that those corals living in cool, relatively agitated water free from silt are more susceptible to the effects of heat, while those which live in the warmer silt-laden shallows are as a rule more resistant. These differences are clearly shown by the following records, taken from his paper, showing the temperatures which caused death in the following species:

Acrophora muricata	34.7° C.	*Mœandra areolata*	36.8° C.
Orbicella annularis	35.6° "	*Porites furcata*	36.85° "
Porites astræoides	35.8° "	*Favia fragrum*	37.05° "
Porites clavaria	36.4° "	*Siderastes radians*	38.2° "

In the case of these cœlenterates it is therefore clear that there is a great divergence in the power of resistance to heat and that (with the exception of *Favia fragrum* which lives in both warmer and cooler water) the resistance is correlated with the temperature of their normal environment.

There can be no doubt that the temperature of the water in shallows occasionally rises very near to the lethal temperatures noted above, especially the lower ones, but it cannot be said without question that it ever becomes sufficiently high actually to kill the corals by heat.

The temperatures which inhibit the functioning of specific tissues in the scyphomedusa, *Cassiopea xamachana* have been determined experimentally by Harvey ('11) who found them to be 39.5° for muscles, 42.6° for sense-organs and 44.0° for nerves. These are closely similar to those mentioned elsewhere for the frog, but Harvey

did not find that heat rigor supervened at this point. The latter was delayed until about 55° which is considerably above the point at which heat rigor appears in the frog (38°–40°) or in mammals (47°–50°) (Vincent and Lewis '01). Indeed, it is much nearer to that reported for the pigeon, which is 53° (Alcock '03).

NEMATODA

Only a single nematode worm has so far been recorded from hot springs. This is *Dorylaimus atratus* which Issel ('06) found in Italian thermal springs. This species was found in water at 40°.

Among the internal parasites of warm-blooded animals there are included also considerable numbers of lowly organized Metazoa all of which live at the temperature of their respective hosts, at or near 40° C. In only a few cases are there any accurate data concerning the reaction of these forms to higher temperatures, but on account of its great importance to the health of the human species, the nematode worm, *Trichinella spiralis*, has been very carefully studied in this respect. As is well known, the encysted larvæ of this species are frequently present in the muscle of swine and reliance may be placed upon the heat of cooking to destroy the encapsulated worms in pork which is to be eaten by man. Various observers, most recently Ransom ('19) have found that the thermal death point for the encysted stage of Trichinella is about 54°, possibly a degree or two lower on somewhat longer exposure. It is therefore quite high for animals in general, but markedly lower than those cited above for encysted Protozoan parasites of man. Moreover there is no increased resistance to heat due to encystment since decapsuled larvæ exhibit the same thermal death point. On longer exposure at lower temperatures of from 39°–40° there is a noticeable difference in the rate of killing if the decapsuled trichinæ have been immersed in pure water or in 0.7% salt solution, as in all cases they become more susceptible to heat after remaining in a hypotonic liquid. Here again therefore, it is evident that imbibition of water by the tissues lowers the thermal death point of the animal.

This change of thermal death point due to the imbibition of water in Trichinella appears to be the same phenomenon that occurs in the spores of bacteria and cysts of Protozoa where dehydration appears to be the reason for a rise in the death point, but the actual temperatures are so different in the two cases that it does not seem that the evidence from the behavior of Trichina can be applied to the others with any degree of assurance.

ECHINODERMATA

Jacobs ('19) has determined the lethal temperatures for starfish larvæ of an undetermined species obtained off the Massachusetts coast, and one consequently not normally exposed to any considerable heat. These determinations were made in connection with experiments to determine the rate of killing and individual acclimatization, but indicate also what lethal temperatures might be for prolonged exposures. Since a water temperature of 32° killed such larvæ in less than an hour, they cannot be able to withstand more than about 30° continuously, which is notably lower than the temperatures observed for tropical corals.

ROTIFERA

The members of this group of minute invertebrates are probably widely disseminated in hot springs, but their presence had seldom been recorded. A few are known from Italian thermal springs through the researches of Issel who has listed the species which he obtained in a paper published in 1906. His list of species, which is reproduced below, with some necessary changes in nomenclature, includes only two forms taken from water of over 40°, so that the group does not seem to be particularly adaptive in this respect. There are twelve, species, as follows:

Rotaria rotaria Pallas 38°.
Rotaria sp. 32–35°.
Metopidia solidus Gosse 40°.
Lepadella triptera Ehrb. 28°.
Monostyla cornuta Müll. 35°.
Distyla inermis Bryce 32–38°.
Colurus loncheres Gosse 32–35°.
Brachionus urceolaris Müll. 32–33°.
Lepidoderma ocellatum Metschn. 38°.
Chætonotus sp. 40°.
Euchlanis plicata Levand. 41°.
Notommata najas Ehrb., var. *thermalis* Issel 45°.

Among these, three at least, *Euchlanis plicata, Monostyla cornuta* and *Lepadella triptera* are fresh water species which occasionally occur in brackish water as they are reported from the saline waters of Oldesloe in Holstein by Hauer ('25). *Brachionus urceolaris* may develop in saline water also (Rumjanzew '22).

ARTHROPODA

Arachnida; Acarina

A single, remarkable species of water mite was obtained in several hot springs in Nevada and California. These were sent to Professor Ruth Marshall who has very kindly examined them and described them as *Thermacarus nevadensis* (Marshall '28).

This species was collected at the following localities:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Bridgeport, Calif.	6	34°	1.0030	7.5
Minden, Nevada	7	45°	1.0000	9.6
Deeth, Nevada	25	43°	1.0008	7.4
Ruby Valley, 65 miles south of Wells, Nevada	28	41.8°	1.0009	9.4

So far as the collection data extend, it it seen that its tolerance for temperatures extends from 34°–45°, for specific gravity 1.0000 to 1.0030 and pH 7.4–9.6.

The mites are of large size, from 2–3 mm. in length, with broad stout body and extremely hard, thick integument. They were numerous in all of the springs where their presence was noted and were generally moving actively about on the surface of the soft mud in shallow water, usually only an inch or two in depth, near the edges of pools in still or very slowly flowing water.

The genus *Thermacarus* contains only one other species *T. thermobius* from Asia and forms the family Thermacaridæ. The old world species was collected in a hot spring near the northern end of Lake Baikal in southern Siberia in 1926 and was described by Sokolow ('27) a year later. It is therefore very surprising to find a second species in hot springs in the hot desert regions of the western United States. At the time Sokolow published his paper he knew of no other record of Hydracarina from hot springs but there is one, mentioned in my previous paper, by Plateau ('70) and only last year Uchida ('27) described an eylaid from a hot spring near Taihoku, Formosa.

This species, *Eylais thermalis* was found in water at 42°. The Asiatic Thermacarus was found in water at 45°, with a hydrogen ion concentration of 8.7, corresponding very closely with the conditions under which we collected the American species. They were found also in quiet water, but were congregated upon the filamentous blue green alga, *Phormidium laminatum*. This led Sokolow to suppose, in connection with the structure of the appendages which would seem to be adapted for clinging to the algæ, that Thermacarus is vegetarian. Most specimens of *T. nevadensis* which we found were, however, not associated with algæ, although in any of the springs such food was present in small amounts.

It appears probable that there is a much earlier reference to *Thermacarus nevadensis*, contained in a paper by Wood ('68) and cited in my previous paper. At that time I was unable to place the "spider-like animal" seen together with larvæ of Chironomus in water at 51° (124° Fahr.), but as these were seen in a hot spring in Owens Valley, California near to one of the localities at which I obtained this mite, Wood's note most probably refers to the same species. His temperature of 51° is considerably in excess of those recorded by Sokolow and myself for either the Asiatic or American species and may be slightly in error.

As Thermacarus occupies an isolated position, it is impossible to draw any conclusions concerning any relationships to other Hydracarina. Eylais is, however, known to occur in brackish water (*cf.* Viets '25).

INSECTS

As might be expected the major part of the fauna of thermal springs consists of insects belonging to several orders. The greatest variety is met among members of the order Diptera, but there are also Coleoptera belonging to several families which are commonly encountered, and the water beetles are perhaps more abundant in both individuals and species than any other insects. As their larvæ are also aquatic such forms enjoy a thermal environment in all stages. This is also true of certain Hemiptera, but the numerous Diptera, dragon flies and other types are of course aquatic only during their preparatory stages and enter a more normal environment in the imaginal condition. As will be seen, the relations of various insects to waters of high temperature are essentially the same as those of the other groups of animals already discussed, but the more detailed data bearing on these phenomena are included in connection with the several groups.

In nearly all of the hot pools which have a temperature higher than that which can be endured by insects, considerable numbers of dead beetles, flies, bugs, wasps and other insects may be seen floating on the surface of the water. No field notes were made concerning such occurrences as they are obviously individuals that have been overcome by heat either by falling into the water or in attempting to enter it from the air in the case of aquatic species. A great abundance of Hydrophilid and Dytiscid beetles was frequently noted, in many cases of species which inhabit the warm water, but have attempted to enter water too hot for them to endure. This is also true of specimens of Notonecta and Corixidæ which are active fliers. Many

spiders are killed in the same way by attempting to skim over very hot water. More careful note was taken in one locality, at Hot Spring no. 8 at Steamboat Springs, Nevada, where several hot pools were dotted with insect flotsam, and a brief list was made of the several types of insects present. This is reproduced below and indicates the presence of a great variety of forms.

The series includes the following and is practically similar to that encountered at other places. *Ephemerida*, grasshopper nymphs, *Odonata*, *Trichoptera*, *Hemiptera* (Saldidæ, Corixidæ, Notonectidæ), *Coleoptera* (Carabidæ Dytiscidæ, Hydrophilidæ, Staphylinidæ, Coccinellidæ), *Hymenoptera* (ants, bees, Psammocharidæ), *Diptera* (Culcidæ, Tabanidæ, Dolichopodidæ, Ephydridæ, Sarcophagidæ, Tachinidæ). In the hot pools near Denio, Oregon and those in the Ruby Valley south of Wells, Nevada the abundance of large water beetles is very surprising, indicating a very high mortality from this cause.

Order Odonata

A considerable series of nymphs of this order were secured during the course of our summer's work from a number of different hot springs. Some of these I have been able to identify specifically with certainty, but have been compelled to indicate only the generic position of others. Altogether nine species were obtained. In my previous account ('24) I have given a summary of some observations on Odonata that develop in hot springs and in brackish or saline water, but there are, in addition, a few references in a paper by Kennedy ('17) which I overlooked at that time. Those which refer to hot springs I have noted below where Kennedy records the nymphs as actually taken in the warm water. He also includes a list of species from the vicinity of the hot springs at Calistoga, Napa Co., California which breed in the more or less warm overflow. Here *Libellula saturata* occurs, a species which I have found flying about hot springs in Yellowstone Park. His records of three species from Pyramid Lake, a highly saline body of water with a specific gravity of about 1.0035 are particularly interesting. These are *Enallagma clausum* Morse, *Ischnura cervula* Selys and *Sympetrum corruptum* Hagen. The last mentioned species I found last summer in Pyramid Lake which we visited on July 26.

Argia

Nymphs of this genus were collected in a number of hot springs. At least two species are included in the series, but as I have been unable to determine the specimens, am compelled to list all in one series as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Goldfield, Nevada	3	35.4°	1.0016	8.0
Goldfield, Nevada	3	37.3°	1.0016	8.0
Denio, Oregon	15	35.2°	1.0000	8.4
Battle Mt., Nevada	23	30.0°	1.0008	8.0
Battle Mt., Nevada	23[a]	36°	1.0021	8.5
Wells, Nevada	26	32.5°	1.0018	7.9

There appear to be no previous records of any members of this genus from thermal springs.

Ischnura

Nymphs of this genus, probably representing two species, were obtained at two localities as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Wells, Nevada	26	32.5°	1.0018	7.9
Grantsville, Utah	30	30.0°	1.0217	7.7

The water in Hot Spring No. 30 which is very close to Great Salt Lake is highly saline. It will be noted that neither of these records indicate any high temperatures and it appears that the members of the genus are not adapted to living in hot or very warm water. Kennedy records the occurrence of two species of Ischnura at Golconda, Nevada in the neighborhood of the hot springs there. This is our Hot Spring No. 18, but we took no nymphs of Ischnura in these springs.

The occurrence of nymphs in Hot Spring No. 30 with a specific gravity of 1.0217 is most unexpected since this salinity is greatly in excess of that which Osburn ('06) found could be endured by unacclimatized dragon-fly nymphs. Osburn determined experimentally that a density of 1.010 was about the limit of salinity for *Libellula auripennis*. This density was taken at 75° Fahr. and would correspond to 1.0136 at 15° C. to which it must be reduced to make it comparable with the records in the present paper. Even with this correction the present record is remarkable.

Celænura

Nymphs belonging to this genus were taken at two localities, as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Osobb Valley, Nevada	21	31.6°	1.0020	8.1
Battle Mt., Nevada	23	30.0°	1.0008	8.0

It is very probable that these are *Celænura denticollis* Burm., since Kennedy ('17, p. 500 and 622) found this species breeding in the overflow from the hot springs at Golconda, Nevada (our no. 18) and at Calistoga, California. The species is common further south and its northern extension is no doubt due to the opportunity afforded by the presence of hot springs. It will be noted that it was taken only in slightly warm water at 30°–31.6°.

Lestes congener Hagen

According to Kennedy ('17, p. 621) this species breeds in the warm springs at Golconda, Nevada (our Hot Spring No. 18), and *Lestes unguiculatus* Hagen probably breeds there also according to the same observer. In the same paper he records a number of other species that occur about these same springs and some of these undoubtedly undergo their transformations there.

Libellula sp.

A number of specimens of nymphs belonging to a species of Libellula which I have been unable to identify were found in five localities as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Hot Springs, New Mexico	1	39.5°	1.0039	8.1
Battle Mt., Nevada	23	36°	1.0021	8.5
Deeth, Nevada	25	——	1.0008	7.4
Wells, Nevada	26	32.5°	1.0018	7.9
Ruby Valley, Nevada	28	41.8°	1.0009	9.4

The nymph is moderately slender, with small eyes, each only about one-tenth as wide as the head. The median lobe of the labium

is produced into a broad tooth at the middle; on each side only very slightly curved, with eight short weak setæ on each side, set in minute emarginations which make the edge slightly wavy or crenulate. There are no mental setæ. Inner edge of lateral lobe regularly serrate, with seven teeth. Lateral setæ seven. Lateral spines of ninth abdominal segment very short, less than one-sixth the length of the segment.

This species will run to Libellula in Needham's recent key of genera, ('27) except that there is a faint crenulation of the edge of the median lobe of the mentum. It is certainly not *L. forensis* which has been reported as present in the neighborhood of Hot Springs at Golconda, Nevada by Kennedy, ('17) as the nymph of this species is known, (Needham '04) and differs at once by the structure of the labium. We collected at the Golconda hot springs, but no dragonfly nymphs were obtained.

Mesothemis simplicicollis Say

Nymphs of this species were taken at three localities as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Hot Springs, New Mexico	1	39.5°	1.0039	8.1
Convict Lake, Calif.	5	43°	1.0012	8.5
Denio, Oregon	15	35.2°	1.0000	8.4

They agree closely with the description given by Needham ('01) of this widespread North American form, the adult of which has been taken by Kennedy at Golconda, Nevada close to the hot springs at that place. We did not obtain nymphs at these springs, however, when we examined them.

Sympetrum corruptum Hagen

A single nymph of Sympetrum was collected in Hot Spring No. 3 near Goldfield, Nevada in water at 35.4°, specific gravity 1.0016 and pH 8.0. It agrees in the structure of the labium with *S. corruptum* as described and figured by Needham ('03) and is probably this species which occurs in this region. It develops in the highly saline and alkaline water of Pyramid Lake whence it has already been reported by Kennedy ('15). The specific gravity of the lake water is given by Kennedy as 1.0035 and is therefore very much greater than that of the present hot spring. This density is probably at the ordinary

temperature of the lake, but unfortunately we did not determine the density at the time of our visit, and a much lighter one, 1.0027, is given in a report of the U. S. Geological survey made in 1870.

Order Ephemerida

Nymphs of a mayfly belonging to the genus Siphlonurus were obtained at two places as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Osobb Valley, Nevada	21	31.6°	1.0020	8.1
Battle Mt., Nevada	23[a]	36.0°	1.0021	8.5

Order Hemiptera

Only a few species of this order are contained in the collections made, but two are of considerable interest. *Ambrysus heidemanni* which I collected in 1923 in Yellowstone Park was obtained again, at Bridgeport, California. A tropical species, *Belostoma apachum* was taken at Paradise, Nevada, and nymphs, probably of the same species were found in hot springs at Battle Mountain, Winnemucca and Wells, Nevada.

For the identification of the Hemiptera I am greatly indebted to Professor H. M. Parshley who examined a miscellaneous series and Professor H. B. Hungerford who determined the Corixidæ and Notonectidæ.

GERRIDÆ

The widespread *Gerris remigis* Say was found in Hot Spring No. 13 in water at 28° at Drakesbad in the Mt. Lassen National Park. In Europe, two species of Gerris have been reported from saline waters by Benick ('26[b]).

SALDIDÆ

Species of Salda (*sens lat.*) are common on the wet soil bordering hot springs and were collected in a number of localities. They can, of course, hardly be considered to belong strictly to the hot springs fauna.

NAUCORIDÆ

Ambrysus haldemanni Montd.

Hot Spring No. 6 in water of 34°, specific gravity 1.0030, pH 7.5, near Bridgeport, California. I have taken this species previously in

Yellowstone National Park in water at 35.5° which was highly charged with silica. It would appear, therefore, that this insect occurs generally in thermal springs of moderate temperature. One of its relatives, *Naucoris cimicoides* of Europe occurs in saline water, but no other members of the family have been found in thermal springs.

Belostoma apachum Kirkaldy

An adult was taken in Hot Spring No. 19 at Paradise, Nevada, in water at 31.8°, and nymphs, presumably of the same species were collected in four other springs. The complete data are as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Denio, Oregon	15	35.2°	1.0000	8.4
Paradise, Nevada	19	31.8°	1.0013	7.5–7.7
Winnemucca, Nevada	21	31.6°	1.0020	8.1
Battle Mt., Nevada	23	30.0°	1.0008	8.0
Wells, Nevada	26	32.5°	1.0018	7.9

This is a tropical form and this fact together with the low temperatures of the springs in which it was taken in Nevada, probably indicates that it is not a typically thermal species, but that it simply extends its range northward through the medium of thermal springs.

NOTONECTIDÆ

This family is represented by two species in our collections, taken in five different hot springs as follows:

Notonecta indica Linn.

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Goldfield, Nevada	3	35.4°	1.0020	8.0
Winnemucca, Nevada	20	36.3°	1.0014	8.6
Osobb Valley, Nevada (Nymphs only in this spring)	21	31.6°	1.0021	8.1
Battle Mt., Nevada (Adult and nymphs)	23	30.0°	1.0008	8.0
Ruby Valley, Nevada (Nymphs only in this spring)	28	33.0°	1.0009	9.4

Notonecta kirbeyi Hungerford

Battle Mt., Nevada	23	30.0°	1.0008	8.0

The data for these two species of Notonecta indicate that they are not very tolerant of high temperatures since they were not found in water above 36.3° although there are in all six records, representing five springs, as the single appearance of *N. kirbeyi* was in company with *N. indica* in Hot Spring No. 23. Also they do not appear to tolerate water of any great salinity as all of the springs in which they were found have a low specific gravity of 1.0008 to 1.0022.

In addition to the record of the European *Notonecta glauca* in a hot spring, cited in my previous paper, there is at least one other earlier record of a notonectid in a thermal spring, in an anonymous note published in 1917 in the Societas Entomologica, Jahrg. 32, p. 26. The writer records *Micronecta episcopalis* in a thermal spring near the Hungarian city of Grosswardein.

One European species, *Notonecta halophila* is a brackish water form, but has been found to be indifferent in this respect and often occurs far from the coast (Hutchison '22). Another, *N. glauca* Linn. is known to invade saline water (Benick '26[b]).

In connection with the presence of hæmoglobin in Chironomus which is one of the characteristic forms occurring in hot springs it is interesting to note that hæmoglobin occurs also in certain Notonectidæ. Its presence in *Buenoa margaritacea* has been noted by Hungerford ('22) who found it localized in groups of cells associated with the trachæ in the abdomen. So far as I know, no species of Buenoa have been reported from hot springs.

CORIXIDÆ

Three species of Corixidæ in addition to an undetermined nymph were collected on the present expedition.

Trichocorixa wallengreni Stal, var.

This was found in two localities, represented in each by numerous individuals.

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Wells, Nevada	28	35.0°	1.0009	9.4
Hot Spring Sta., Utah	31	35.3°	1.0146	8.2

Arctocorixa tumida Uhler

Two lots were secured, consisting of numerous individuals from the following localities:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Silver Peak, Nevada	4	37.2°	1.0212	8.3
Convict Lake, California	5	35.0°	1.0012	8.5

Arctocorixa wileyi Hungerford

This species was taken at a single locality and the individuals were not numerous. Denio, Oregon, Hot Spring no. 16; temperature 39°; specific gravity 1.0015; pH 8.5. The species was described from the Wasatch Mts. in Utah.

Corixid nymph

Two specimens. Twenty-nine miles south of Winnemucca, Nevada in Hot Springs no. 20; temperature 36.3°; specific gravity, 1.0014; pH 8.6.

Members of this family were thus found living in six different hot springs at temperatures from 35° to 39.6°, only the species of Arctocorixa in water of any considerable temperature (39°–39.6°). So far as the water of these springs is concerned, in two cases this is unusual. At Silver Peak, Nevada the specific gravity is quite high (1.0212) and also at Hot Springs Station, Utah (1.0146) and in both places larvæ of the brine fly, Ephydra, were present with the Corixids. Schwarz ('91) reports a species of Corixa from brackish water near Great Salt Lake, Utah, which is probably *Arctocorixa decolor*, Uhler, a western species known to occur in saline pools (Packard '71). Previous records of European and North American Corixidæ in thermal springs are cited in my earlier paper.

Some interesting observations on the occurrence of Corixidæ in brackish water in England have been made by Thorpe ('27). He finds that some species live in saline water, but that there is a great difference in their ability to survive in this medium as one species, *Corixa selecta*, is unharmed by a density of 1.040 whereas *C. sahlbergi* cannot withstand more than 1.008. In such cases, however, it is not the resistance of the adult that limits the distribution of species, but the possibility of the nymphs developing under such conditions (*cf.* Poisson '24). Thorpe concludes from his observations

that Corixidæ are very sensitive to changes of salinity, although as already indicated, some are very resistant to high concentrations. Arctocorixa is represented in the saline waters of Oldesloe in Holstein by three species according to Benick ('26[b]).

Order Coleoptera

The collections of beetles obtained include thirty-one species represented by adults and a smaller number of larvæ. Among the material are members of the five common families of water-beetles, the Haliplidæ, Dytiscidæ, Gyrinidæ, Hydrophilidæ and Helmidæ as well as some mud-beetles of the family Heteroceridæ. Ten of the thirty-one forms were taken at more than one locality, *i.e.*, in from two to eleven different hot springs, respectively.

In the list of these which follows, I have indicated the localities by the Hot Spring numbers which have been given to them on a previous page (p. 143), and have included the temperature and hydrogen ion concentration of the water from which the beetles were actually taken. In a few cases the temperature is not cited, where it was impossible to get it accurately because of some physical difficulty.

In the preceding table only collections made at temperatures of 30° C. (86°) Fahr.) or above are recorded as it appears that temperatures below this point are no higher than those which occur frequently in shallow pools of non-thermal origin in these hot desert regions. Above 30° there is a range of 15.7 degrees to 45.7°, the highest temperature at which any species of beetle was found. Within this rather wide range the occurrence of species may be roughly grouped as follows:

30.0–35°	17 species	42.1–43°	2 species
35.1–37.5°	10 species	43.1–44°	1 "
37.6–40°	13 "	44.1–45°	1 "
40.1–42°	5 "	above 45°	2 "

As might naturally be supposed there is a gradual reduction of species with ascending temperature. This shows very clearly in spite of the necessarily restricted number of observations and the fact that a continuous gradation of temperatures is never available under suitable conditions for observation. If these data are added to indicate the number of species which we found to invade water of gradually increasing temperatures, they form a very regular curve (Fig. 3).

Indeed, its regularity is surprising, considering the small number of observations, the great variation in the several ecological factors

List of Aquatic Coleoptera

	Spring No.	Temperature °C	Specific Gravity	pH
HALIPLIDÆ				
Peltodytes callosus Lec.	11	——	1.0016	5.7–6.5
DYTISCIDÆ				
Laccophilus decipiens Lec.	20	36.3	1.0014	8.6
Laccophilus mexicanus	28	——	1.0009	9.4
Bidessus affinis Say	28	38–42.5	1.0009	9.4
Bidessus affinis Say	9	41.0	1.0012	8.5
Bidessus affinis Say	16	39.0	1.0015	8.5
Bidessus affinis Say	26	32.5	1.0018	7.9
Cœlambus thermarum Darl.	20	38.0	1.0014	8.6
Cœlambus thermarum Darl.	23[a]	30.0	1.0021	8.6
Cœlambus bruesi Fall	28	39.2–40.0	1.0009	9.4
Cœlambus sp.	28	35.6	1.0009	9.4
Cœlambus lutescens Lec.	16	39.0	1.0015	8.5
Deronectes striatus Lec.	6	34.0	1.0030	7.5
Deronectes striatus Lec.	22	34.5	1.0014	7.8
Agabus griseipennis Lec.	23[a]	36.0	1.0021	8.5
Agabus griseipennis Lec.	16	39.0	1.0015	8.5
Rhantus sp. near *divisus* Aubé	16	39.0	1.0015	8.5
Dytiscus marginicollis Lec.	23	30.0	1.0008	8.0
Cybister sp.	21	31.6	1.0020	8.1
GYRINIDÆ				
Gyrinus maculiventris Lec.	28	33.0	1.0009	9.4
HYDROPHILIDÆ				
Ochthebius bruesi Darlington	24	38.8	1.0020	9.6
Ochthebius interruptus Lec.	26	32.5	1.0018	7.9
Helophorus lineatus Say	23	30.0	1.0008	8.0
Helophorus lineatus Say	23[a]	36.0	1.0021	8.5
Berosus infuscatus Lec.	23[a]	36.0	1.0021	8.5
Hydrophilus triangularis Say	16	39.0	1.0015	8.5
Tropisternus dorsalis Brullé	16	35.8–39.0	1.0015	8.5
Tropisternus dorsalis Brullé	19	32.2	1.0012	7.5–7.7
Tropisternus dorsalis Brullé	20	36.3	1.0014	8.6
Tropisternus dorsalis Brullé	23	30.0	1.0008	8.0
Tropisternus ellipticus Lec.	6	34–38.5	1.0030	7.5
Tropisternus ellipticus Lec.	16	35.8	1.0015	8.5
Tropisternus californicus Lec.	22	34.5	1.0014	7.8

List of Aquatic Coleoptera—continued

	Spring No.	Temperature °C	Specific Gravity	pH
Hydrobius fuscipes Linn.	23[a]	36.0	1.0021	8.5
Paracymus subcupreus Say[1]	9	44.5	1.0012	8.5
Paracymus subcupreus Say[1]	19	31.8	1.0012	7.5–7.7
Paracymus subcupreus Say[1]	28	——	1.0009	9.4
Philhydrus hamiltoni Horn	5	43.0	1.0012	8.5
Philhydrus hamiltoni Horn	9	45.5	1.0012	8.5
Philhydrus hamiltoni Horn	11	——	1.0016	5.7–6.5
Philhydrus hamiltoni Horn	12	30–35	——	5.1
Philhydrus hamiltoni Horn	28	40–41.5	1.0009	9.4
Philhydrus nebulosus Say	6	——	1.0030	7.5
Philhydrus nebulosus Say	8	33.0	1.0030	8.0
Philhydrus nebulosus Say	13	28.0	1.0021	6.7
Philhydrus nebulosus Say	14	40.2	1.0019	7.6
Philhydrus nebulosus Say	15	35.2	1.0000	8.4
Philhydrus nebulosus Say	19	31.8	1.0012	7.5–7.7
Philhydrus nebulosus Say	20	38.0	1.0014	8.6
Philhydrus nebulosus Say	23[a]	36.0	1.0021	8.5
Philhydrus nebulosus Say	24	40.5	1.0020	9.6
Philhydrus nebulosus Say	27	40.0	1.0017	7.1
Philhydrus nebulosus Say	28	35.6–38.2	1.0009	9.4
Laccobis agilis Rand.	5	43.0	1.0012	8.5
Laccobis agilis Rand.	10	38.5	1.0014	6.7
Laccobis agilis Rand.	11	——	1.0016	5.7–6.5
Laccobis agilis Rand	12	30–35	——	5.1
Laccobis agilis Rand.	22	34.5	1.0014	7.8
Laccobis agilis Rand.	24	38.8	1.0020	9.6
Laccobis agilis Rand.	27	40.0	1.0017	7.1
Laccobis agilis Rand.	28	38.0–39.5	1.0009	9.4
Laccobis agilis Rand.	33	35.8	1.0021	7.4
Laccobis agilis Rand.	34	40.2	1.0024	9.0
HELMIDÆ				
Helmis similis Horn	15	32.5	1.0000	8.4
Helmis thermarum Darlington	15	32.5	1.0000	8.4
HETEROCERIDÆ				
Heterocerus brunneus Mels.	27	40.0	1.0017	7.1
Heterocerus collaris Kies.	28	——	1.0009	9.4

[1] I am able to record the occurrence of this species also from water at 45.7° in a hot spring northeast of Bear Lake in southeastern Idaho. These specimens were given me by Mr. A. C. Burrill who collected them, and identified by Mr. H. C. Fall.

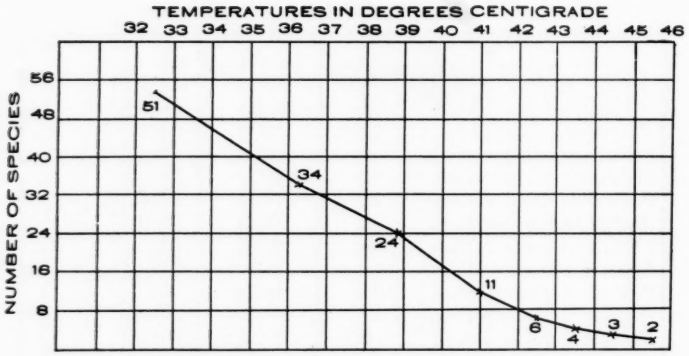

FIGURE 3. Graph illustrating the number of species of water-beetles collected in hot springs at temperatures from 32° to 46°, showing the gradual elimination of species and reduction in the fauna as the temperature increases.

such as climate, soil, altitude, composition of water, etc., and the varied types of springs, streams and pools in which the species were living. It demonstrates very clearly that temperatures above 30° or thereabouts offer a great barrier to colonization by water-beetles and that there is a successive elimination of the less highly adaptable species as the temperature rises. Most of the elimination seems to take place, at least in the western desert regions studies, between 30° and 45°.

Only five species were taken in water above 40°. They are *Bidessus affinis*, *Paracymus subcupreus*, *Philhydrus hamiltoni*, *Philhydrus nebulosus* and *Laccobius agilis*, and all except the Paracymus were found a number of times in water of lower temperature.

The highest temperature of 45.7° was noted in the case of *Paracymus subcupreus*. This is not so high as a few others reported from various other springs in different parts of the world, but apparently no beetles have ever been found living in water above 46°, except in some records that are possibly slightly in error.

The larvæ of a number of species of water-beetles of the families Dytiscidæ and Hydrophilade were obtained. I have been able to identify these to the genera with the aid of the excellent keys contained in Wilson's recent paper (Wilson '23) and they are listed below.

	Hot Spring No.	Temperature	Specific Gravity	pH
Hydroporus sp.	20	38.0°	1.0014	8.6
Agabus sp.	16	35.8°	1.0015	8.5
Agabus sp.	23[a]	36.0°	1.0021	8.5
Agabus sp.	28	39.5°	1.0009	9.4
Tropisternus sp.	5	35.43°	1.0012	8.5
Tropisternus sp.	6	35.°	1.0030	7.5
Tropisternus sp.	20	38.°	1.0014	8.6
Tropisternus sp.	26	32.5°	1.0018	7.9
Philhydrus sp.	27	40.0°	1.0017	7.1

It will be noted that the temperatures listed for the larvæ are considerably lower on the average than those at which adults of several species were found. It is easily possible, of course, for the adult beetles to enter water temporarily and leave it later, and it appears that some of the records for adults may be in water hotter than that in which larvæ can develop. As the number of records for the larvæ is rather small, it is however not possible to be positive on this point.

In my previous paper ('24), I gathered together all the references known to me relating to the occurrence of Coleoptera in hot springs, but since that time have discovered a few that were overlooked as well as some that have been published since that time.

In a note published nearly fifty years ago, Tournier ('79) gave some notes on a species of Laccobius which he discovered in abundance in the hot baths at Baden and described as *L. thermarius* which has since been placed as a synonym of *L. gracilis*. This species was then regularly to be found in the baths at 28°, but came in with the water from the springs at said to be 47.5–49° which was later allowed to cool. As noted above and in my previous paper, other species of Laccobius have been since discovered in the thermal fauna both in Europe and America.

The series of Cœlambus known to occur in hot springs and brackish waters has been augmented by a species lately described by Wallis ('24) as *C. salinarius* which occurs so far as known only in an alkaline lake at Baldur, Manitoba, in Canada, and Benick ('26[a]) has reported the European *C. ennæagrammus* and C. *lautus* from saline water.

Aside from the aquatic beetles there are also some riparian or subaquatic species which occur occasionally on the warm or hot soil about the springs. Most noticeable among these are tiger-beetles, Cicindela.

Several forms of these were commonly observed flying about over the damp soil in which their larvæ excavate their burrows. Two species are represented in the collections. The first, *C. longilabris* Say, var. *perviridis* Schp., was abundant in Lassen Park, and in Bumpass Hell we saw them about the borders of the hot springs in considerable numbers. The second, *C. carthagena* Dej., is much more widespread in the hot springs areas at lower altitudes and is represented by three varieties, *hæmorrhagica* Lec., *bisignata* Dokh. and *pacifica* Schp. The first was collected about hot springs, No. 5, 18, 20 and 31 and seen flying about many of the others. About hot spring no. 31 at Hot Springs, Utah, we found larval burrows in great abundance in the warm soil about the borders of the stream which flows from the spring. The burrows extend into the soft soil nearly to the ground water level and at the time of our visit (Aug. 23) were inhabited by larvæ in various stages of growth. The other two varieties, which lack almost or entirely the maculations on the elytra were seen much less commonly and collected only about Hot Spring No. 5, near Convict Lake, Cal.

The European *Cicindela littoralis*, var. *nemoralis* evidently displays, at times, a similar fondness for the soil about hot springs. Many years ago, Lucas ('79) found this species very abundant along the banks of small rivulets on the Island of Eubœa in the Ægean Sea where the overflow from hot saline springs was flowing into the sea.

A few Carabidæ were collected about the borders of the hot springs, but no attempt was made to obtain a representation of this fauna which does not appear to be in any sense a thermal one. In desert regions such as these a considerable part of the water is of thermal origin and search for moist soil must lead very generally to such situations.

The following is a list of the few species collected, with the localities:

Dyschirius varidens Fall, Goldfield, Nev. (Hot Spring No. 3.)
Bembidion breve Mots., Lassen Park, Cal. (Hot Spring No. 11.)
Bembidion epphipigerum Lec., Goldfield, Nev. (Hot Spring No. 3.)
Bembidion nigripes Kby., Wells, Nev. (Hot Spring No. 28.)
Bembidion tumidum Lec., Wells, Nev. (Hot Spring No. 28.)
Bembidion flavopictum Mots., Wells, Nev. (Hot Spring No. 28.)
Bembidion dubitans Lec., Wells, Nev. (Hot Spring No. 28.)
Tachys (*Tachyura*) sp. near *incurvus* Say., Wells, Nev. (Hot Spring No. 28.)
Platynus funebris Lec., Lassen Park, Cal. (Hot Spring No. 12.)

Since the publication of my earlier paper where attention was

called to the similarity of the coleopterous fauna of thermal waters and that of brackish water, a very interesting and carefully considered paper has been published by Walsh ('25) on the maritime and brackish water beetles of the British Coast. In his account Walsh groups the species into two main and several subsidiary categories. As his list is so similar to the list of hot springs Coleoptera, I have reproduced it below.

1. Brackish water species
   Haliplus apicalis Thom.
   Philhydrus bicolor Fabr.
   Berosus spinosus Stev.
   Ochthebius exaratus Muls.
2. By no means restricted to brackish water, but often occurring in fresh water also.
   a. Found indifferently in fresh and brackish water
      Cœlambus parallelogrammus Ahr.
      Dytiscus circumflexus Fabr.
      Hygrobia (*Pelobius*) *tarda* Hbst.
      Enoclerus bicolor Payk.
      Helophorus intermedius Muls.
      Helophorus mulsanti Rye.
      also under certain circumstances, *Hydroporus palustris* Linn.
      Agabus bipustulatus Linn.
      Haliplus ruficollis Deg.
      Hydrobius fuscipes Linn.
      Helophorus viridicollis Steph.
   b. Species (in Great Britain) almost entirely restricted to brackish water, but on the continent occurring in fresh water also.
      Laccophilus variegatus Germ.
      Philhydrus maritimus Thoms.[1]
   c. Species restricted to brackish water throughout Europe.
      Ochthebius marinus Payk.[1]
      Haliplus striatus Sharp.

A comparison of this list which contains representatives of thirteen genera, with the present list of thermal water beetles and published records of the latter shows that all but two of the genera listed above occur in hot springs and one of these (Hygrobia (= *Pelobius*)) does not occur in North America. It will be seen from these lists that the composition of the thermal and saline faunas is extremely similar in the case of the several species of water beetles taken as a whole. One noticeable difference in the two series is the occurrence of Hel-

[1] According to Thorpe ('27) these two species are at home in pools liable to a density of 1.035 or more.

midæ in thermal springs, at least in the United States and their general absence in the saline environment. This may probably be accounted for however, as suggested to me by Mr. P. J. Darlington, by the fact that these beetles generally require freely running water and such conditions are practically absent in brackish water.

Within the past several years numerous observations and experiments have been made upon the effect of heat upon beetles of non-aquatic habits which are of considerable interest in relation to the fauna of thermal springs.

The larva of the scarabæid beetle, *Cotinis nitida* which lives in burrows excavated in the soil has been found by Miss Hintze ('25) to select soil of high temperature in preference to that which is cooler. Thus she found that larvæ of this species, when given a choice, selected soil at a temperature of 39–40° C., leaving almost without exception places where the temperature was noticeably lower.

Snyder and St. George ('24) have recently determined the temperatures fatal to the lyctid beetle, *Lyctus planicollis* Lec. As these determinations were made by heating the insects in large pieces of wood for a brief time, the exact temperatures of the insects themselves were not known, although doubtless noticeably below that of the chamber in which they were heated. They found that a half hour's exposure at 120° F. (49° C.) did not kill all of the larvæ but that, as might be expected without question, an additional half-hour at 130° F. (59° C.), resulted in killing all of the insects.

Welch ('24) finds that the lethal temperature for adults and larvæ of the furniture beetle, *Anobium striatum* is between 45° and 47°. An exposure of one minute at 45° proves fatal to the majority of individuals and none are able to withstand 47° for the same length of time in moist air.

Many Coleoptera develop in the bark or wood of trees, and on account of the greater amount and variety of food materials in the layers just beneath the bark, a large percentage of them lie in what may be termed the subcortical layer. When the prostrate logs in which many of the species occur are exposed to the rays of the sun they become greatly heated and the temperatures to which these forms are subjected frequently become excessive. Craighead ('21) and Graham ('21; '22) have investigated the conditions which prevail in this subcortical layer and find that the temperature may at times exceed 60° C. which is of course fatal to all insect life. Observations on a number of species living beneath bark show that 48° is in general the average temperature which is fatal to the majority, but that

there is considerable variation among different species and probably also a much less variation between individuals of the same species. Graham states that adults of the buprestid beetle, *Chrysobothris dentipes* behave normally up to 51°, but above this enter a state of coma or estivation and succumb at about 52°. This larva he believes to be able to withstand even greater heat than the imagines. A bark-beetle, *Pityokeines sparsus* is more readily affected by heat, becoming inactive above 43° and dying at 47°.

Either of these temperatures (47° and 52°) is rather high, especially the latter, and certainly suggests that some acclimatization had taken place among the members of the subcortical fauna, especially in Chrysobothris which like most Buprestidæ is notoriously heliophilic in the adult state. In the case of most of these insects there is a considerable amount of moisture present beneath the bark so that conditions here compare more closely with the aquatic environment than they do where the atmospheric humidity is low and where the effect of dessication induced by heat must be taken into consideration.

Graham has later ('24) extended his work on the lethal temperatures for three species of beetles whose larvæ develop beneath the bark of logs. These are the large cerambycid, *Monochamus scutellatus*, a bark-beetle, *Ips pini* and a buprestid, *Chrysobothris dentipes*. Among these there is considerable variation as the lethal temperature was found to vary from 43° to 52°, with an average of 47°–50°. In each of the three species he found a range of about five to seven degrees between the point at which the more susceptible and more hardy individuals succumbed, so that if we make a reasonable allowance for the probability of error necessarily attendant upon such experiments there remains a sufficient individual variation to permit of a selection of individuals. We may thus expect to find an increased tolerance of heat in those species which live beneath bark where the temperature may frequently exceed the maximum death temperature by some ten degrees. That selection has not been able to proceed far, is, however, only too evident for the maxima of 49°–52° are but little above the tolerance of species which have had no opportunities for selection nor acclimatization. They are, on the other hand, far above those tolerated by animals which live in a medium that is always far below such temperatures.

Order Trichoptera

In my earlier account, mention is made of a New Zealand caddis fly which lives in the sea, inhabiting rock pools. The habits of this species were described by Hudson ('04) and in his recent book Tillyard

('26) gives figures of the imago and larval case of this remarkable insect, *Philaniscus plebejus* Walk. which is a member of the family Sericostomatidæ.

Order Diptera

This order is better represented than any other in the thermal fauna and in my present collections six families are represented, including the Culcidæ, Chironomidæ, Stratiomyidæ, Tabanidæ, Syrphidæ and Ephydridæ.

Culicidæ

Larvæ of mosquitoes are usually to be found in thermal water, but so far as my experience extends, never at very high temperatures. The present collections contain three species.

Culex tarsalis Coquillett

Larvæ of this species are represented in the collections from six localities, as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Hot Spring, N. Mex.	1	39.0°	1.0039	8.1
Convict Lake, Calif.	5	35.2°	1.0012	8.8
Minden, Nevada	7	30.0°	1.0000	8.8
Battle Mt., Nevada	23	36.0°	1.0008	8.0
Battle Mt., Nevada	23[a]	36.0°	1.0021	8.5
Wells, Nevada	26	34° –35.2°	1.0018	7.9
Ruby Valley, Nev.	28	35.6°	1.0009	9.4

This species has been reported twice previously from thermal springs in Yellowstone Park by Dyar ('23) and Brues ('24) and is undoubtedly one which readily adapts itself to such conditions. It is clearly a species restricted to alkaline water, however, as no specimens were taken in water of a lower pH than 7.9. Some of the records show that it develops in rather warm water also as one series was taken at 39.0°.

Aedes stimulans Walker

A single larva, apparently of this species, was obtained in Hot Spring No. 31 at Hot Springs Station, Utah in water of 35–35.3°. The specific gravity of the water in this spring is rather high (1.0146) and the pH 8.2.

Culiseta incidens Thomson

This common and widespread mosquito breeds in a variety of situations and has been reported before from thermal waters.

In 1927 we collected a single larva in Hot Spring No. 26[a] near Wells, Nevada in water at a temperature of 33.3° C., with a hydrogen ion concentration of 6.9 and charged with hydrogen sulphide. This water was not at all saline (specific gravity 1.0015).

A previous record of the occurrence of this species in thermal waters is by Dyar, who found the larvæ breeding in pools charged with hydrogen sulphide at Banff, Alberta. The same observer ('23) found the larvæ of the related *C. inornata* Williston in Yellowstone Park, breeding in "extinct hot springs, which have grown cold and dirty, with slight emission of gas." *C. incidens* has been found breeding in highly brackish water also by Hearle ('26). In this case the dirty salt pools where he found the larvæ had a density of somewhat more than half that of sea water. It would appear unquestionably to be a species which requires a low hydrogen ion concentration.

Aedes dorsalis Meigen

This species was present in almost incredible numbers at Wendover, Utah, where their presence made a study of the springs practically impossible. This is Hot Spring No. 29, of moderate temperature, 27–28°. The specific gravity is 1.0041, less than might be expected at the edge of the Great Salt Desert. This species was undoubtedly breeding there as there is no other water within many miles. It develops regularly in alkaline and saline waters as described in my previous paper ('24, p. 394).

Chironomidæ

A considerable number of larvæ and two pupæ of a species of Culicoides or some closely related genus, probably Dasyhela, were collected at Beowawe, Nevada in Hot Spring no. 24. These were taken in the overflow from one of the geysers in water at a temperature of 39.6° and the pupæ at 38.8°.

The pupæ are very similar to those of *Dasyhela longipalpis* Kieff and undoubtedly the species is closely related. The respiratory horns on the thorax are about two-fifths as long as the body, with thickened, slightly capitate tips and are finely transversely striated, due to the presence of an encircling tænidium; each bears about 21 minute stigmal openings which appear as minute black dots forming a series on the upper side of the tube. The anal protuberances are

very acute and are directed laterally, perpendicular to the median line, each slightly longer than one-half the length of the last abdominal segment. The pupæ are dark reddish brown, with light yellowish, black tipped respiratory tubes.

This seems to be the first recorded instance of members of this genus in thermal waters, so far as I am aware, but one European species, *D. halophila* Kieffer has been reared from salt water (Rohde '12; Thienemann '26). Many species of Culcoides develop in fresh water and others occur in brackish water, and according to Rieth ('15) records of this genus in brackish or salt water date back to an account published in 1771 by O. F. Müller. The water from which the present specimens come showed a specific gravity of 1.0020 and hydrogen ion concentration of 9.6. In his recent paper ('26), Edwards mentions specifically two species of Culicoides *C. morium* Lutz and *maculithorax* Williston bred from the brackish water of mangrove swamps in the American tropics, and Thorpe ('27[a]) finds that *C. nubeculosus* breeds in pools along the British coast below high-water mark. Likewise Rieth has described several tropical brackish water species (*C. marium, C. insignis,* etc.).

The first record of a species of this group in alkaline water is cited in my earlier paper. Packard ('71) reported a Tanypus, which was referred to Ceratopogon, *sens lat.* by Johannsen, from an alkaline pond near Clear Lake, California.

Tanypus monilis Linn or a related species. (Fig. 4; 2, 3)

The larva of *Tanypus monilis* has been described and figured by Johannsen ('05, p. 136 and plate 19, fig. 14) and again by Malloch ('15, p. 375 and plates 24, fig. 25, and fig. 7).

The specimens before me agree in most essential particulars with the characters given for this European species which is recorded from the eastern United States and from as far west as South Dakota. They are red in life however and not yellow with brown marking as described by Johannsen. I have figured the labium and antennæ and the entire larva.

The localities are as follows: Goldfield, Nevada (Hot Spring No. 3), in water at 35.4°; sp. g. 1.0022; pH 8.0; Convict Lake, California (Hot Spring No. 5) in water below 35°; sp. g. 1.0012; pH 8.8.

Tanypus sp. (Fig. 4; 4, 6)

Larvæ of a species of Tanypus quite different from the preceding were taken at Hot Springs, New Mexico (Hot Spring No. 1) in water at 39.5°; sp. g. 1.0039; pH 8.1. In the form of the labium it resembles

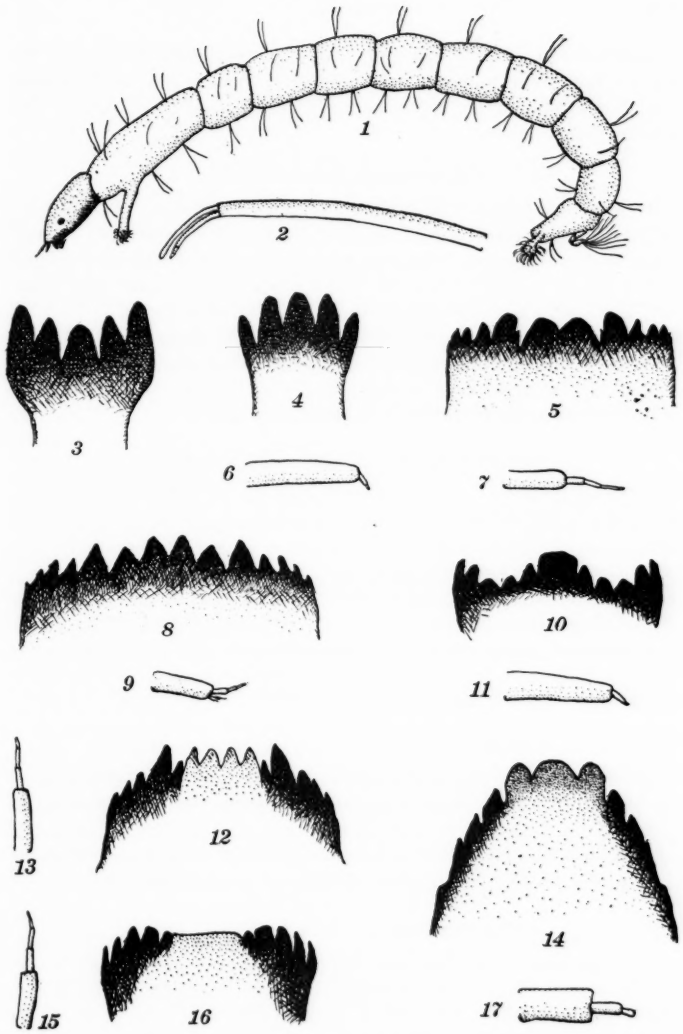

FIGURE 4. Details of larvæ of Chironomidæ. 1. *Tanypus monilis*, or related species, lateral view of larva; 2, antenna of same; 3, labium of same; 4, Tanypus sp., labium; 5, Chironomus, sp. no. 1, labium; 6, Tanypus sp., antenna; 7, Chironomus sp. no. 1, antenna; 8, Chironomus sp. no. 2, labium; 9, antennae of same; 10, Chironomus? sp. no. 3, labium; 11, antenna of same; 14, Cricotopus sp., labium; 15, Orthocladius sp., antenna; 16, labium of same; 17, Cricotopus sp., antenna.

somewhat Johannsen's figure of *Tanypus carneus* Fabr. ('05, pl. 20, fig. 6), but the antennae of the present specimens are much shorter and the head scarcely twice as wide as long. I have figured the labium and antenna.

Chironomus tentans Fabr.

One series of larvæ from Convict Lake, California, (Hot Spring No. 5) taken in water at 35° appear to be this species without reasonable doubt. They are identical with a form that I collected several years ago in thermal water in Yellowstone Park, except that there are only two pairs of ventral blood-gills instead of three.

The larvæ of *C. tentans* normally have two, but those which I figured ('24) as doubtfully this species from Yellowstone Park have an additional smaller third pair anterior to the two larger ones. Whether all represent a single species it is impossible to say.

Chironomus sp. No. 1. (Fig. 4; 5, 7)

A series of larvæ taken at Hot Spring no. 28 in the Ruby Valley, 65 miles south of Wells, Nevada, represent probably a species of Chironomus. They were taken in water at a temperature of 42°.

The mentum (Fig. 5) is quite unlike that of any American species of which the larvæ are known, but from its general form suggests the genus Chironomus. The eyes are completely divided into two parts, the anterior prolegs quite short and with pale yellow bristles. The two median teeth of the labium are usually quite distinctly paler than those on each side.

Chironomus sp. No. 2. (Fig. 4; 8, 9)

A single larva taken in Hot Spring no. 12, near Brokeoff Mountain in Lassen National Park, California resembles that of *Chironomus flavus* Johannsen but is undoubtedly not that species. The labial dentition (Fig. 8) is similar in general type, but by no means identical. The antennæ (Fig. 9) are about as long as the mandibles.

Chironomus sp. No. 3. (Fig. 4; 10)

A single larva from Beowawe, Nevada (taken in Hot Spring No. 24 at 39.5°) I cannot place with any degree of certainty. The labium is of peculiar shape (Fig. 16) and quite different from that of any species that seems to have been described.

The entire thorax and abdomen are thinly clothed with sparse, long, very delicate hairs. These are more abundant on the abdomen

and on the thorax are intermixed with a small number of shorter, much stiffer hairs or bristles. The dorsal tufts of setæ on the ninth abdominal segment are attached to unusually long protuberances, fully three times as long as thick.

Chironomus sp. No. 4. (Fig. 4; 12, 13)

Larvæ of this species of blood-worm which appears to be a species of Chironomus were taken first at Hot Springs, New Mexico and later at seven other localities.

The labium of this form (Fig. 12) resembles that of certain Chironomus like *C. digitatus* in general structure and it probably belongs to this genus.

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Hot Springs, New Mexico	1	38.7°	1.0039	8.1
Goldfield, Nevada	3	37.3°	1.0022	8.0
Convict Lake, Calif.	5	43.0°	1.0012	8.5
Steamboat Springs, Nevada	8	33.0°	1.0030	8.0
Beowawe, Nevada	24	40.5°	1.0020	9.6
Wells, Nevada	26	32.5°	1.0018	7.9
Wells, Nevada	27	40.0°	1.0017	7.1
Ruby Valley, Nevada	28	40.0°	1.0009	9.4

Orthocladius sp. (Fig. 1; 15, 17)

A series of larvæ taken at Steamboat Springs, Nevada, in Hot Spring No. 8 at a temperature of 33° are apparently a species of Orthocladius. The labium is similar in form to that of an undetermined species from Illinois figured by Malloch ('15) as Orthocladius sp. B.

Species of this genus are known in Europe to occur in the sea and in brackish water along the sea coast Theinemann ('15), Kieffer ('00), Potthast ('15), Mercier ('23) and Edwards ('26).

Cricotopus sp. (Fig. 4; 14, 17)

A considerable series of larvæ and pupæ from Beowawe, Nevada are more or less like *Cricotopus varipes* Coq. as described by Johannsen ('05, p. 256, plate 25, fig. 22) and may even be this species which is known from the eastern United States and the State of Washington. They were taken in water at 38.8° in the overflow from one of the

small geysers of Hot Spring no. 24. This water is strongly alkaline, with a pH of 9.6 or above and specific gravity of 1.0020.

The larvæ are 5–6 mm. in length with very dark head, the antennæ as figured (Fig. 17) and the labium (Fig. 14) with three central teeth that are quite distinctly paler than the lateral ones which are four in number on each side. The three thoracic segments are much lighter than the others (red in life and pale yellow after preservation) and the abdomen of quite dark grayish color. The anal gills are unusually small. Thoracic prolegs very short and stout, densely clothed with unusually dark spines; anal prolegs with the spines mostly dark in color.

The labium of the larva is very similar to that of a form figured by Malloch ('15, plate 29, fig. 21) as Orthocladius, but as Malloch did not rear the adult, the generic reference is doubtful.

There are several representatives of this genus known from brackish or salt water in Europe (*cf.* Thienemann, '15).

A complete discussion of marine Chironomidæ has very recently been published by Edwards ('26) in which he adds several new species in the genera Clunio and Tanytarsus and describes a most remarkable genus, Pontomyia from Samoa. In the latter the male has the wings reduced in size and the legs modified for swimming under water while the female retains a pupiform condition, without wings, mouthparts, thoracic segmentation or antennæ. Provided with only four vestigial legs she is incapable of movement. This truly marine insect was discovered by Buxton who has given an account of it as "the only known insect which is submarine in all stages" ('26), together with some interesting remarks on the colonization of the sea by insects.

A comparison of the effects of salt water upon the larvæ of the common house mosquito, *Culex pipiens* and an unidentified Chironomus larva has been undertaken by Koch and Gofferje ('20) and they find that in these fresh water species that the Chironomous larvæ withstand a salinity four or five times as great as the Culex larvæ and moreover that this relation exists with reference to both the chlorides and sulphates of sodium, potassium, magnesium and calcium. Their observations thus show conclusively that the reason for the migration of Chironomidæ into the sea and alkaline waters depends upon a primary difference in reaction toward liquids of high osmotic pressure, rather than a greater adaptability for gradual acclimatization to a saline medium. Furthermore, the same students have found that several other fresh water invertebrates, Daphnia Cyclops, and Chloë (a mayfly) are affected by salinity in approximately the same way as *Culex pipiens* which shows that the Chiro-

nomus type is unusually resistant in comparison to some other fresh water types of crustaceans and insects.

STRATIOMYIIDÆ

Fourteen lots of larvæ, representing nine species were obtained in ten of thirty-four hot spring areas from which we obtained collections. In most cases only a single species was obtained at each place although one (Hot Spring No. 10) yielded four species all belonging to different genera.

In the accompanying table the several series are listed and it will be seen that stratiomyiid larvæ were found under the most varied conditions of temperature, ranging from 28° to 50°.

Hot Spring	Temperature	S. G.	pH	Name
No. 1	38.7°	1.0039	8.1	Odontomyia sp. no. 1.
No. 4.	39–46.7°	1.0212	8.3	Odontomyia sp. no. 2.
No. 5.	35°	1.0012	8.5	Stratiomyia No. 1.
No. 8.	33°	1.0030	8.0	Odontomyia No. 4.
No. 10.	43–47°	1.0014	7.3	Odontomyia No. 5.
No. 10.	43–47°	1.0014	7.3	Stratiomyia No. 2.
No. 10.	43–47°	1.0014	7.3	Oxycera sp.
No. 10.	43–47°	1.0014	7.3	Nemotelus sp.
No. 11.	30–40°	1.0016	5.7–6.5	Stratiomyia No. 1.
No. 13.	28°	1.0021	6.7	Stratiomyia No. 1.
No. 18.	49–50°	1.0008	8.1	Odontomyia No. 3.
No. 20.	38°	1.0014	8.6	Odontomyia No. 4.
No. 22.	38°	1.0014	7.8	Odontomyia No. 2.
No. 22.	38°	1.0014	7.8	Odontomyia No. 4.

Only one species was found at the upper limit, but all the genera and many of the species were represented in one or more collections made in water at 40° of above. A considerable variety of forms were found at from 43–47° which would seem to be about the upper range of tolerance as only one species exceeded this.

As far as the specific gravity of the water is concerned, there is a considerable range of salinity, from 1.0012 in Hot Spring No. 5 to 1.0212 in Hot Spring No. 4 which is highly saline. This is not surprising, however, since several stratiomyiids are known to develop in brackish water or even in the sea (*vide* Brues, '24, p. 398).

With reference to the acidity or alkalinity of the water a considerable range was observed in the habitats of the species which we ob-

tained. Thus while most of the series were in water of rather high hydrogen ion concentration (7.8–8.6), several were collected in more acid water with a pH ranging from 7.3 to 6.5–5.7. In the series of pools in Hot Spring No. 11, the pH ranged from 6.5–5.7, unfortunately our record does not indicate at which one the larvæ of Stratiomyia No. 1 were found. In comparison with the other data, it seems probable that they were in the more alkaline ones.

Stratiomyia sp. No. 1. (Fig. 5; 5.)

A large species, length 30–35 mm. Rather thinly hairy above and below, with the sides bare except for a patch of three bristly hairs on each segment at the lateral margin. Penultimate and antepenultimate segments unarmed, without marginal hooks. Dorsum of each body segment with a transverse row of four bristly hairs between the middle and apex and on the posterior half of the body; also with a single dorsal pair in front of the row; underside of segments with the row of four but lacking the more anterior pair. Terminal segment rather long, about four times as long as wide, quite noticeably tapered from a broad base to the middle, parallel beyond; above with a pair of bristles near the middle, set very close to the lateral margin and with another bristle at each posterior angle; below with a widely separated pair just behind the base of the anal slit, a pair behind the slit, another pair at apical fourth and a terminal pair; anal slit terminating before the middle of the segment. Body very dark, above with faint traces of narrow alternating stripes of pale and dark.

There are three series of this species. Near Convict Lake, California (Hot Spring No. 5) taken in water at 35° or below, specific gravity 1.0012 and pH 8.5; Bumpass Hell, Mount Lassen National Park, California (Hot Spring No. 11) in water at variable temperatures from 30°–40°, specific gravity 1.0016, pH 5.7–6.5 (varying with amount of H_2S); Drakesbad, Mount Lassen National Park, California (Hot Spring No. 13), in water at 28°, specific gravity 1.0021, pH 6.7.

Stratiomyia sp. No. 2

Rather small larvæ, 10–13 mm. in length. Sparsely hairy above and below; lateral protuberance of each segment with four or five slender, bristly hairs. No hooks on the penultimate or antepenultimate segment. Body hairs on segments confined, both above and below, to a central area on each segment. Terminal segment about three times as long as broad, the apex of the anal slit before the middle of the segment; above with a pair of bristles before the middle, placed one near each lateral margin; another pair beyond apical

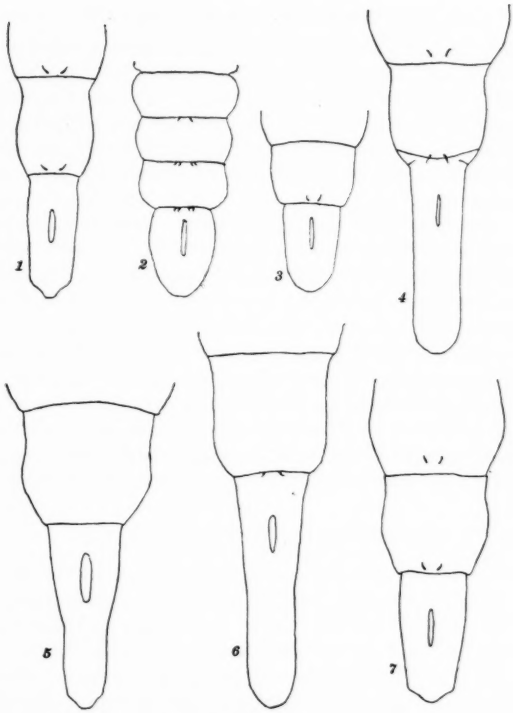

FIGURE 5. Posterior segments of body of larvæ of Odontomyia and Stratiomyia in ventral view. 1, Odontomyia sp. no. 2; 2, Odontomyia sp. no. 5; 3, Odontomyia sp. no. 3; 4, Odontomyia sp. no. 1; 5, Stratiomyia sp. no. 1; 6, Odontomyia sp. no. 4; 7, Odontomyia sp. no. 2.

third, well separated, and one at each posterior corner; below with a curved transverse row of four before the anal slit; a well separated pair beyond middle; another pair at apical third and a smaller subapical pair. Color dark gray above, with very obsolete striping of pale and dark indicated most clearly at the apices of the segments. Underside much paler.

Several specimens from Brokeoff mountain (Hot Spring No. 10) Mount Lassen National Park, California, in water at 43–47°, specific gravity 1.0014, pH 7.3.

Odontomyia sp. No. 1. (Fig. 5; 4)

A large species, the well grown larva 20–30 mm. in length. Penultimate and antepenultimate segments each with a pair of ventral hooks at the middle of the posterior edge. Terminal segment very long, about five times as long as wide (the segment is slightly widened in the figure, due to pressure in mounting); apex of anal slit at the basal third of the segment. Each segment with a rather dense patch of stiff hairs above and below, and laterally with a group of three having a very few finer hairs intermixed. Terminal segment with sparse, scattered bristly hairs; a pair at apical fourth above and a subterminal pair more widely separated behind these; a lateral bristle at middle; three pairs below, one near base, one at middle, and one at apical third. Body mottled with dark above, the markings forming seven more or less well defined longitudinal vittæ. Three specimens from Hot Springs, New Mexico (Hot Spring No. 1) at a temperature of 38.7° with specific gravity of 1.0039 and pH 8.1.

This larva will run to *Odontomyia cincta* in Johannsen's key, ('22) but the last segment is much more elongate and there is no distinct dorsal broad pale stripe while the lateral margin of the body is pale, not dark.

Odontomyia sp. No. 2. (Fig. 5; 1, 7)

A moderate sized species, the larger larvæ not over 20 mm. in length. Penultimate and antepenultimate segments each with a pair of hooks at the middle of the posterior edge. Terminal segment of moderate length, scarcely three times as long as broad. Apex of anal slit at, or just behind the middle of the segment. Body hairs on all the body segments long and rather sparse, confined to the anterior half of each segment on the fore part of the body; bristles near lateral margins of segments generally placed one in front and one behind, rather than in a group of three. Each segment below, especially the apical ones, with a distinct transverse series of four bristles behind near the middle. Apical segment with bristly hairs; a row of four in front of anal slit; one at each side of the middle of the slit; a transverse row of six just behind the slit; a subapical pair and one near each hind angle. Above, this segment bears a group of 8–10 at each side near base; several pairs on the disc basally; a median pair at basal fourth; a widely separated pair at apical fourth and one near each apical corner. Color of body quite dark, especially above, somewhat lighter laterally as the anterior corners of the segments are much paler. No distinct vittæ except for the broad darkening of the dorsum.

Numerous specimens, many of them not fully grown from Silver

Peak, Nevada (Hot Spring No. 4) in quite cool water (28°–30°) with a rather high specific gravity of 1.0212 and pH of 8.3. They were taken together with a species of Ephydra.

A second lot of many specimens is from the same place (Hot Spring No. 4) but from warm water ranging from 39.6°–46.7.°

A third lot from Brokeoff Mt., Mount Lassen National Park, California (Hot Spring No. 10) in water of 43°–47°, specific gravity 1.0014 and pH 7.3.

Another series from 26 miles south of Battle Mountain, Nevada (Hot Spring No. 22) may be the same species. The water of this spring is scarcely saline, specific gravity 1.0014, temperature 38° and pH lower (7.8).

Odontomyia sp. No. 3. (Fig. 5; 3)

Length about 15–18 mm. represented by two puparia not in a good state of preservation and not sufficiently perfect to describe in detail. The terminal segment is very short, scarcely twice as long as broad, with the apex of the anal slit just beyond the middle of the segment. Penultimate segment with a pair of hooks medially at the posterior margin; antepenultimate unarmed.

Golconda, Nevada (Hot Spring No. 18) in water at a temperature of 49°–50° (not alive and possibly killed by the heat of the water). Specific gravity of water 1.008 and pH 8.1.

These larvæ are much like those of *O. cincta* and *O. vertebrata* figured by Hart from Illinois ('95).

Odontomyia sp. No. 4. (Fig. 5; 6)

A large species, length from 25–35 mm. Penultimate segment with a pair of hooks at middle of posterior margin, antepenultimate unarmed. Terminal segment very long and slender, about five times as long as broad (somewhat broader in the figure as the mount has become flattened). Anal slit terminating well before the middle of the segment. Body quite densely clothed with bristly hairs which form a broad transverse band around the middle of each segment. Lateral margin of body with many bristly hairs, but none conspicuously larger than the others, except on the more anterior segments which bear one or two larger bristles. No rows of larger bristles on the segments above or below. Terminal segment with bristly hairs as follows: a very widely separated pair just before middle, a widely separated pair at apical fourth and one near hind angle; below with one at each side of anal slit; two pairs behind the middle, the posterior

pair farther apart, a subapical pair placed near the lateral margin and one at each hind angle.

Color dark, more or less mottled dorsally and with a well-marked, narrow, median, dorsal stripe bordered by a narrow, whitish stripe on each side.

There are two series of this species; one from 29 miles south of Winnemucca, Nevada (Hot Spring No. 20) temperature 38.0°, specific gravity 1.0014, pH 8.6, and the other from 26 miles south of Battle Mountain, Nevada (Hot Spring No. 22), temperature 38.0°, specific gravity 1.0014, pH 7.8.

Another lot of larvæ from Steamboat Springs, Nevada (Hot Spring No. 8) may be the same. They are very similar, but have the terminal segment slightly shorter and broader. They came from water at 33°, specific gravity 1.0030 and hydrogen ion concentration 8.0.

Odontomyia sp. No. 5. (Fig. 5; 2)

Two very small and undoubtedly only partly grown larvæ measure 5–6 mm. in length but seem unquestionably to represent another species. The penultimate and antepenultimate segments each bear four stout hooks at the middle of the posterior margin below. They are about the size and form of Euparyphus, but the antennæ are clearly placed at the anterior angles of the head. Body nearly bare above, with only a few sparse and very minute hairs; below with a few much stouter, short, horn-like bristles that form a more or less transverse row of four or six on each of the five anterior body segments; segments behind these with a broad anterior patch of such bristles in addition. Four strong, thorn-like hooks at the middle of the posterior border of the penultimate and antepenultimate segments; also a pair on the preceding segment. Lateral edge of each body segment with several long, flexuous hairs. Terminal segment scarcely twice as long as broad, its apical fringe as long as the segment; dorsally with four bristles, one pair before middle and another before apex, these bristles placed quite close to the lateral margins. Beneath with a curved row of four before the anal slit; with apparently several pairs behind the anal slit and a subapical pair; anal slit long, its apex beyond the middle of the segment. Color dark above, not at all longitudinally striped although paler laterally; below somewhat lighter.

There are two specimens from Brokeoff Mountain, Mount Lassen National Park, California (Hot Spring No. 10) at a temperature of 43–47°, specific gravity 1.0014, pH 7.3.

Oxycera (?) sp. (Fig. 6)

Length 3–4 mm. Dark brownish above, mottled with paler, especially toward the sides; below uniformly much paler. Head with the antennæ set well behind the anterior angles of the head and about halfway between the lateral margin and the median line. Body surface shagreened as usual in the family, without hairs, except for a few stout glistening, white, delicate bristles arranged in a regular pattern. Above, the thoracic segments each bear a transverse row of four in front of the middle, extending only halfway to the sides; six basal abdominal segments each bearing a single pair placed behind the middle and nearer to the median line than to the lateral margin; penultimate segment with only a few minute bristles at apex. Below

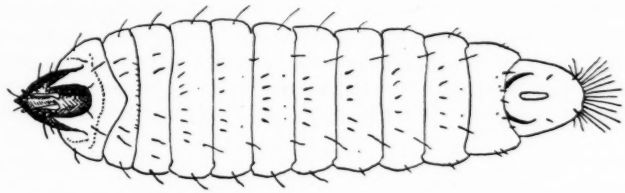

FIGURE 6. Larva of Oxycera sp., ventral view.

the thoracic segments bear a small number of bristly hairs, more numerous on the metathorax; each of the six basal abdominal segments bears a transverse row of small thorns or short hooked spines, usually six in number and behind these a row of about six small bristles, the armature of these segments extending only about halfway from the median line to the lateral margin; in addition along the lateral line each segment bears a single bristle; penultimate segment with two long hooks nearly as long as the segment. Terminal segment about as long as broad; middle of anal slit just before the middle of the segment. Apical bristles pectinated, scarcely as long as the segment.

One series of larvæ from near Brokeoff Mt. (Hot Spring No. 10), Mount Lassen National Park, California, at a temperature of 43–47°, specific gravity 1.0014 and pH 7.3. They were taken together with Stratiomyia sp. No. 2.

These larvæ may belong to Euparyphus as they agree with the descriptions given by Johannsen of several North American species. On account of the very large hooks on the penultimate abdominal segment the species would seem to be close to the North American *E. brevicornis* Loew. They do not agree at all with figures of larvæ

of the genus Oxycera given by Johannsen nor with the characters given in his table as Oxycera is said to have a terminal spiracular opening. However Lenz ('23) has described the larvæ of European species of Oxycera and these appear to be closely similar to the larva I have just described. So this is probably referable to Oxycera and not to Euparyphus. Lenz ('26) has since recorded two European species of Oxycera (*O. meigeni* and *O. trilineata*) from saline waters at Oldsloe in Holstein.

Nemotelus sp. (Fig. 7)

Length 4.5–5 mm. Body light colored above and below, but dorsally with some darker mottling which takes the form of a narrow transverse band on the second and third thoracic segments and the apical three or four abdominal ones. Those on the thorax near the middle of the segments and those on the abdomen subapical; in addition the abdominal segments each bear a pair of oblique marks which diverge from the anterior margin and together form a more or less triangular dark area with the center and posterior edge pale. Head

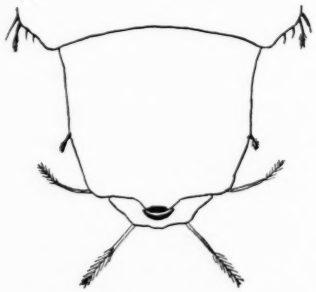

FIGURE 7. Larva of Nemotelus sp., posterior part of body

narrow, more than twice as long as wide, with the antennæ placed well in front of the middle and considerably removed from the lateral margin. Body clothed with a number of large, isolated, bristly hairs and with some fine, recumbent pubescence. The head bears a number of short broad, more or less spatulate bristles, one in front of each antenna and three in a curved series on each side of the head; each body segment with a short curved bristle on the lateral margin, near the middle, or behind it on the posterior segments; below these on the ventral side is another, the same size and further inward, halfway

to the median line a much longer one, except on the last segment, which bears only several short ones on each side of the anal slit; each ventral segment with a transverse band of fine short pubescence. Dorsal surface apparently with a short, more or less bulbously enlarged bristle on each segment between the median line and lateral margin, but these are so obscured by a soft deposit not removable by acid that only a few are clearly to be made out. Terminal segment (fig. 7) with four long bristles at apex.

One series of larvæ were taken in Hot Spring, No. 10, near Brokeoff Mt., Mount Lassen National Park, California, at a temperature of 43–47°, specific gravity 1.0014, pH 7.3.

These are undoubtedly larvæ of a species of Nemotelus as they agree closely with the figure given by Johannsen ('22) of an European species described by Lundbeck ('07), and with a more recent description of the European *N. notatus* Zett. given by Lenz ('23).

There are at least two types of peculiar body bristles on these larvæ, those on the terminal segment and the other long ones on other parts of the body are plumose apically while many of the shorter ones are blunt apically, spatulate, dilated or almost bulbously enlarged.

To the earlier references on the occurrence of Stratiomyiidæ in thermal springs, there may be added another, contained in a brief, but interesting note by Lucas ('79). It relates to the larvæ of an undetermined species of Stratiomyia (or possibly an Odontomyia), which were obtained on the island of Eubœa off the eastern coast of Greece in hot saline springs at a temperature of 35°–40°.

Nemotelus uliginosus of Europe is known to develop in saline water whence it has been reported by Schmidt ('13).

TABANIDÆ

Six lots of larvæ belonging to this family were taken in hot springs at five different localities. The specimens vary greatly in size, but all are structurally alike and similarly colored and may be referred without question to *Tabanus punctifer* O.S. which is a very common and widely distributed species in this region. I have already recorded its occurrence in thermal springs in Yellowstone Park (Brues, '24) and it is known to breed generally in alkaline waters throughout the West (Webb and Wells '24). The adults were seen flying at a number of other places and at one of these near the hot springs at Silver Peak, Nevada, may breed in the thermal water. No larvæ were collected here however and there are cold pools and marshes

near these springs from whence they may have come. Following is a transcript of the data relating to this species.

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Convict Lake, Cal.	5	43.0°	1.0012	8.5
Bridgeport, Cal.	6	36–38.5°	1.0030	7.5
Winnemucca, Nev.	20	38.0°	1.0014	8.6
Beowawe, Nev.	24	39.6°	1.0020	9.6
Hot Springs, Utah	31	35.3°	1.0146	8.2
Ogden Canyon, Utah	32	——	1.0063	8.3

There is a very considerable range in the temperatures at which this species was found, which is to be expected as it occurs abundantly in cold water. The range in specific gravity is quite considerable also, since two of the springs emit comparatively fresh water (1.0012–1.0145). The pH (8.2–9.6) is consistently high, except in one case where it is only 7.5.

No tabanid larvæ were found in the hot springs near Denio, Oregon or north of Winnemucca, but *Tabanus punctifer* is a very abundant species in the Antelope Valley where they have been found by Webb and Wells (*l.c.*) to develop together with *T. phænops* in Alkali Lake and the swampy area nearby.

SYRPHIDÆ

A single series of larvæ of a member of this family was taken in Hot Spring No. 26[a] near Wells, Nevada in water with a temperature of 33.3°, and specific gravity of 1.0015. The pH is very low, 6.9, and the water has a foul odor due to H_2S.

The larvæ are of the characteristic rat-tailed type of Eristalis and Helophilus and since they are very similar to those of *Eristalis* (*Lathryophthalmus*) *aëneus*, evidently belong to this genus. Members of this group live in the larval stages in foul water and no doubt the parent flies are attracted by the hydrogen sulphide odor which is very pronounced in this spring. As the body bristles are usually trifid, and only in part bifid, and as the anal gils have a larger number of lobes, these larvæ are probably not *E. aëneus*, and I have appended a description of the specimens before me.

Body about 9–10 mm. in length; width about 2 mm.; narrowed apical portion behind the anal gills somewhat longer, 12–15 mm.

The integument is very irregularly folded into transverse ridges which show here and there three small slender curved bristles usually arising from a small papilliform elevation. The bristles arise very close together, almost from a common base, and as they are generally trifid, form a stellate group, especially noticeable about the posterior end of the body. In some places the bristles are bifid or Y-shaped. The body anteriorly above at the sides bears numerous, closely placed, minute spines and below on each side of the anterior segment is a large convex papilla-like swelling similarly spined with hooked, claw-like spines intermixed. In a median cavity above there are the antennæ, each composed of a large, short, basal joint, a tubular second one about twice as long as thick and a minute rounded apical joint. Presumably the large first segment represents the prothorax as the spined swelling on each side below appears to be homologous with the prolegs on the six following segments. These prolegs are smaller on the next five segments, and each bears along its anterior edge a series of about eight stout hooked spines or thorns followed by a similar row of smaller ones behind which are two more or less irregular rows of much more minute and less clearly hooked spines. The prolegs of the last pair are connected by two rows of stout hooks and the arrangement of spines is reversed as well as their insertion, as these curve forward at their tips, while the others are curved backwards. Just behind the last prolegs there arise in a depression the anal blood gills each of which is provided with six digitate extensions. As in *Eristalis aëneus*, as figured by Metcalf, the posterior extension of the body is transversely wrinkled on the tapering basal portion, finely longitudinally aciculate, on the middle part while the posterior part appears to be transversely marked with extremely minute lines which represent the tænidia of the two tracheæ that extend through it. The fringed bristles of the apex are slightly damaged, but appear to be essentially as in *Eristalis aëneus*.

Rat-tailed larvæ of this type have several times been found in saline water or in the sea, and I have given several records in my earlier paper, but apparently this is the first record of their occurrence in thermal water. As there noted (*l.c.* p. 404) *Eristalis aëneus* has been bred from salt pools on the English coast.

The lethal temperature for at least one species of Syrphidæ has been determined in connection with the treatment of bulbs for the destruction of *Merodon equestris*. With this species it has been found (Mackie '27) that 43.3° (110° Fahr.) is sufficiently high to destroy the larvæ in a very short time.

EPHYDRIDÆ

Larvæ of Ephydra, possibly representing more than one species, were collected at several localities as follows:

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Silver Peak, Nev.	4	cool	1.0212	8.3
Convict Lake, Cal.	5[a]	43.0°	1.0012	8.5
Minden, Nev.	7	——	1.0000	9.6
Hot Springs Sta., Utah	31	35.3°	1.0416	8.2
Ogden Cañon, Utah	32	——	1.0063	8.3

These larvæ come from a variety of types of water and their occurrence in springs such as Nos. 5, 7 and 32 is quite unexpected since the species of Ephydra are usually restricted to water with a high degree of salinity. The water from springs Nos. 4 and 32 fulfills this expectation and possibly that from No. 32, but the springs at Minden and Convict Lake are not at all saline, in fact the former showed no salts in solution so far as could be detected with an hydrometer. At least one species of Ephydra, *E. subopaca* Lw of the eastern United States has been found by Ping ('21) to be incapable of development in fresh water. The optimum concentration of salt water for the European *Ephydra riparia* according to Thorpe ('27) is 1.026, or approximately that of sea-water.

It will be noted that all of the collections listed above came from water with a hydrogen ion concentration of 8.2 or over, and that in only one case were larvæ found in water of really high temperature (43° in Spring No. 5[a]).

In Iceland, Böving ('25) refers to the occurrence of an undetermined species of Ephydra in a hot water creek in Oräfa, at a temperature of "more than 40° C."

Some years ago Poynton ('04) gave an account of some dipterous larvæ which he found in great numbers in siliceous hot springs in New Zealand. These springs are near Lake Taupo and are known as black terraces since the flowing water deposits black sinter. In these basins the larvæ were living in masses of filamentous algæ, and Poynton noticed that the floating puparia after the emergence of the adult flies drift to the edge of the pools and serve as a basis for the deposit of the sinter which borders the pools and forms the terrace, thus the flies unwittingly aid in the development of the terraces

through their discarded puparia. The larvæ are described as about half as large as those of a blow-fly, dark grayish green, and shaped curiously like a shark with its double lobed tail. The adult flies were identified for him by Hutton as *Opomyza* n. sp., but his description fits the larva of Ephydra so well, that there would seem to be little doubt that the insects belong to this or some closely related genus.

From the numerous records presented above, it is evident that Ephydra very frequently invades the hot spring environment.

Mollusca

Snails were less abundantly represented in our collections than had been expected as only four species were obtained and only five localities yielded specimens. I am indebted to my friend, Mr. William J. Clench of the Museum of Comparative Zoology for the determinations.

Physa cooperi Tryon

Convict Lake, California, Hot Spring No. 5, temperature —°, specific gravity 1.0012, pH 8.5.

Physa smithiana Baker

Minden, Nevada, Hot Spring No. 7, temperature —°, specific gravity 1.0000, pH 9.6 or over.

Physa virginea Hald.

Locality	Hot Spring No.	Temperature	Specific Gravity	pH
Hot Springs, N. Mex.	1	38.7°	1.0039	8.1
Beatty, Nevada	2	38.2°	1.0016	7.2
Monroe, Utah	34	35.5°	1.0024	9.0

Lymnæa palustris desidiosa Say.

Minden, Nevada, Hot Spring No. 7, temperature —°, specific gravity 1.0000, pH 9.6 or over.

I am at a loss to account for the apparently erratic distribution of this series of molluscs as the several localities seem to have no characteristics in common. Since only five of the thirty-four hot springs visited afforded any specimens, however, it seems certain that there is some very good reason for their absence in the others. It will be

seen that the specific gravities vary from fresh to 1.0039 and the hydrogen ion concentration from 7.2–9.6 (7.2–9.0 in the case of *Physa virginea*). These conditions do not, therefore, indicate barriers of a physical nature and there is good reason to believe that it cannot be an absence of lime in the other springs.

Very recently Clench ('26) has described *Physa johnsoni* from Hot Sulphur Springs at Banff, Alberta Canada. The temperature of the water in which this species was found is not recorded.

Henderson ('25) has rediscovered the Physa described by Cockerell ('89) as *Physa heterostropha cupreonitens* at the type locality near Wellsville, Colorado and from other hot springs near Nathrop, Colo., about 20 miles further up the Arkansas River found *Physa sayi warreniana* in warm water at a temperature not recorded.

Böving ('25) records small snails as plentiful in Oräfa, Iceland, in a hot water creek at a temperature of "more than 40° C." It is probable that these may have been a species of Limnæa.

VERTEBRATES

Fishes

There are very few references to the presence of fishes in hot springs and the accuracy of most of these is extremely doubtful. There is no need to repeat them here, as I have cited them in my previous paper.

We found fish in only one of the hot springs areas visited during the summer but the circumstances under which they occurred are very interesting. At Hot Springs, New Mexico (Hot Spring No. 1) there is a small stream which runs through a ditch that carries off the combined flow of several of the springs at this place. It flows rapidly and is of an almost perfectly uniform temperature of from 38.7–39.5°. Here, where the water averages 39.5°, we saw considerable numbers of a small cyprinid fish, *Notropis lutrensis* (Baird and Girard). The fish are regularly present in the stream as we were informed by some small boys who told us of their occurrence when they saw us collecting aquatic insects in the water at the head of the stream. The fish were actively swimming about and behaving in a perfectly normal manner. This water has a pH of 8.1. *Notropis lutrensis* is a widely distributed species inhabiting the basins of several rivers in the Southwestern states from South Dakota southward (Evermann and Kendall ('94) and Jordan and Evermann ('96) and is especially abundant in the Rio Grande basin.

The temperature recorded above agrees closely with the data.

relating to several European fishes and confirms my previous opinion that 40° represents a close approximation to the critical point of heat endurance for fishes. This is quite high, considering the fact that many forms undoubtedly succumb at temperatures between 30 and 40°.

Issel ('06) has reported *Gasterosticus aculeatus* at 29–30° in Italian hot springs and a variety of *Barbus callensis* (var. *figuigensis*) has been described by Pellegrin ('13) from artesian water at the Figuig Oasis in Morocco in water at 30°.

In several of the thermal springs of North Africa *Cyprinodon fasciatus* C. V. has been found in water as high as 40° or thereabouts. Cyprinodont fishes are quite commonly represented in saline or brackish water.

Amphibia

A single frog was collected during the course of the summer. This has been very kindly identified for me by Mr. Arthur Loveridge as *Hyla regilla* Baird and Girard. It was taken in Hot Spring No. 16 at Denio, Oregon, but as the spring is about six miles south of the town it is really located in the extreme northern part of Nevada. The pool in question is surrounded by a small marshy area with coarse grass and has a temperature of 35.8°; specific gravity 1.0015 and pH 8.5. As this group of springs is separated by several miles of desert country from any non-thermal water the species undoubtedly breeds regularly in the warm springs.

The frog and the tadpoles of toads have been the object of a considerable amount of investigation with respect to the effect of high temperatures. As mentioned in my former paper ('24) they show a very definite reaction to temperatures at or near 40° C., which not only cause death but induce definite changes in the muscles and nervous tissues. At that time I overlooked an important paper by Cameron and Brownlee ('15) describing experiments of the same kind. They were able to confirm in the main the observations of the older investigators, showing that in the case of late winter and early spring individuals of *Rana pipiens* in Canada, the resistance to high temperatures was even less than has been found previously. In this case they found that an internal temperature of 39.5°, corresponding to 44° external temperature was completely fatal in 25–30 minutes. After exposures of an hour, 29°–30° internal temperature was fatal if the frogs were immersed in water but 32°–33° was necessary if they were in air saturated with water vapor for the same length of time. This difference appears to be constant and they cannot

account for it. It may, however, I think be readily explained on the basis of a greater heating of the superficial tissues when immersed in water. They found also that temperatures of one or two degrees above 18° C. proved fatal within a few days. This is not in accordance with former observations on other frogs and the authors think that this may be due to the fact that the material studied had recently emerged from the hibernation period.

These observations accord very closely with those of Maurel and Lagriffe ('00); Vernon ('99) and the ones of Alcock ('03) who showed that 40° is fatal to frog nerve, and of Vincent and Lewis ('01) and Vrooman ('07) who found that temperatures of 38°–40° induce a heat rigor in frog muscle through a coagulation of proteins present in the muscle fibre during life. After such coagulation, recovery is of course impossible, so that the lethal temperature limit is a definite point which may vary only through a change in the coagulability of these proteins. That such variations exist seems probable in the light of the acclimatization phenomena and they may even be periodic with reference to the seasons of hibernation and activity.

Since my previous account appeared, I have seen another reference to the occurrence of batrachians in brackish water. Rose ('25), in a paper on the habits of some South African frogs, states that the Plathander frog (*Xenopus lævis*) can survive in brackish water, and he determined experimentally that a concentration of about 10 grams to the litre of water was sufficient to kill them after an immersion of four days.

Professor Pearse has also called my attention to a paper of his own (Pearse '11) which I had previously overlooked. This relates to a species of Rana in the Philippines which he found developing in the water of salt flats that contained sodium chloride at the rate of 14.8 grams per litre. Tadpoles were numerous in this medium which contained numbers of both young and nearly metamorphosed individuals.

The ability of a least one frog to withstand salt water was known to Darwin when he wrote the Origin of Species as he refers (6th edition, p. 414) to a species of frog from India which is not killed by salt water, in connection with his comments on the lack of batrachians in insular faunas.

PLANT LIFE

Bacteria

The occurrence of various algæ in thermal springs is so general that it has attracted the attention of numerous naturalists and I have

given a brief outline of the observations made on these thermal plants in my earlier paper. These date from the latter part of the eighteenth century when their presence was noted in hot springs in Europe, to the more explicit and careful observations of recent botanists such as Setchell ('04) in the hot springs of Yellowstone Park, which I was able to confirm from studies in the same locality.

There is also a very extensive and, of course, more recent literature relating to the existence of a great variety of bacteria in hot springs. These are of very general biological interest because they represent a type of thermophilous microörganisms which have also been found to be very generally distributed in other environments and commonly under conditions which would not suggest that they were really thermophilous. These microörganisms are mainly bacteria, but include some yeasts and other fungi whose optimum temperatures for development are very noticeably higher than those of other types of living organisms. Their optima are indeed above or quite near the lethal temperatures for other bacteria and other types of animal and plant life in general.

Our knowledge of this group of organisms begins with papers by Van Tiegham ('81), Globig ('87) and a study by Miquel ('88) who isolated and described *Bacillus thermophilous* which he found to be quite generally distributed in sewage, other water, in the air and in the alimentary canal of man and other animals, and it has since been found in soil. This organism grows at temperatures between 42° and 70°, but its optimum lies between 65° and 70°. Its discoverer was unable to account for its presence in places where it must develop very slowly at temperatures below those at which he was able to cultivate it. Recognizing that this organism multiplied and flourished at temperatures which coagulate protoplasm, Miquel quite naturally ascribed to it some peculiar type of protoplasm which was not affected by temperatures fatal to all other forms of life, except the spores of bacteria which were known at that time to survive heat far above the coagulation point of the protoplasm of growing organisms.

A very considerable flora of similar bacteria was made known through the researches of Cohn ('93), Mac Fayden ('94), Miss Tsiklinsky ('03[a]), Miehe ('07; '19), Kruyff ('10), Nègre ('13[a]) and other recent workers.

These show in general the same relations to temperature; their optimum range for growth lies well above that for normal animals and plants and the growth of some species is not inhibited by temperatures between 70° and 80°.

Similarly, the bacterial flora of hot springs includes a variety of

forms which behave in the same way and are in some cases identical. These have been obtained in numerous localities and studied by a series of bacteriologists; Certes and Garrigon ('86), Karlinski ('95), Teich ('96), Spallicci ('97), Myioshi ('97[a]) ('97[b]), Tsiklinsky ('02 and '03), Falcioni ('07), Nègre (13[b]), *et al.*

In at least one case they have been found alive in water at 83° and the presence of bacterial growths in pools in Yellowstone Park as high as 89° indicates that some species are able to develop at this temperature. Schmidt and Weis ('02) also refer to a blue green alga, (p. 144), living in water above 90°. On the other hand the bacteria found in hot springs of comparatively low temperature are not necessarily thermophilous forms as some of them are restricted to the lower temperatures at which animal life occurs.

The wide distribution of these thermophilous bacteria precludes any assumption that they are the results of acclimatization to excessively thermal environments since such high temperatures occur consistently in nature only in hot springs or in the fumaroles and hot soil associated with volcanic phenomena. Miehe and others have shown that fermenting hay and the dung of animals when greatly heated in the process of fermentation develop an actively growing flora of thermophilous organisms.

Aside from their marked ability to withstand excessively high temperatures or even to multiply under conditions, some thermal bacteria seem to require an unusual amount of heat for their existence. Three species of Bacterium, *B. ludwigii*, *B. calfactor* and *B. ilidzensis capsulatus* which were isolated by Karlinski ('95) from thermal springs at Ilidze in Bosnia, occur normally in water as hot as 80°.

Of these, *Bacterium ludwigii* was found by its discoverer to be unable to survive at a temperature below 50°.

There is also a great mass of data relating to bacteria which shows that the thermal death point rises with an increase in the osmotic pressure of the culture medium. That is to say, a hypotonic liquid such as distilled water which tends to increase the amount of water in the organisms, lowers the thermal death point, while an increased osmotic pressure raises the death point. Such an affect is easily seen in cultures of the abundant *Micrococcus aureus*. This species is not killed by a temperature of 65° in water, physiological salt solution nor broth containing 16% sucrose on an exposure of half an hour, but when the temperature is raised to 70° or 75° there is a noticeable drop in the surviving bacteria, more pronounced in the distilled water; finally at 80°, all in water are killed, but a few survive in the two other media (Robertson '27). The same was noted for *Streptococcus*

thermophilus, but here the difference is more pronounced as a treatment for the same period in distilled water and physiological salt solution showed no survival in water at 70°, and large numbers of individuals alive in the salt solution.

That this is a generally prevalent condition is shown by studies on numerous other bacteria by various workers and also in the case of spores the same effect has been observed by Viljoen ('26) in their resistance to heat. The phenomenon appears to be due without question to the higher coagulation point of albumin or similar substances when partially desiccated.

One type of environment presents a suitable substratum for the growth of microörganisms at high temperature. This is the bark and subcortical tissues of logs which regularly reach temperatures of 60° or more under the influence of the sun's rays. When sufficiently moist they rapidly disintegrate through the action of various mircoörganisms and fungi. This then furnishes one suitable type of substratum and may account for the presence of certain thermophilous forms which occur in soil and in the alimentary tract of animals.

With due consideration to the several possibilities it is difficult to evade the conclusion that the resistance to heat of thermophilous bacteria is a primordial trait retained in these microörganisms from previous ages when conditions of excessive heat were much more prevalent and extensive than they are at the present time. It is no doubt such considerations as these which led Mereschkowsky ('10; '20) to consider that there are two distinct types of protoplasm in living organisms, distinguishable physiologically by their resistance to heat, and corresponding so far as bacteria are concerned to a series including the psychrophilic and mesophilic forms as distinguished from the thermophilic types. Since the maximum growth temperatures for the former are near 43–45° and the minimum for the latter are approximately the same, there is a rather clear cut division into two groups possible on the basis of temperature alone.

Algæ and Higher Plants

Among the primitive algæ which occur in thermal springs by no means all are able to exist at the higher temperatures known to support plant life. One blue-green alga, *Mastigocladus laminosus*, which is widely distributed in thermal springs of Europe, Asia and North America is almost as sensitive to heat as the non-thermal types of plants and animals. This species grows normally in water having a temperature of 52° or less and has been shown experimentally to thrive in cultures (Löwenstein '03) between 19.3° and 51° C., but

not above that point. It is quite evidently a form which has migrated into the thermal environment from the freshwater flora and its temperature relations are fundamentally different from those of Phormidium and similar types of blue-green algæ that occur in water of very high temperature.

That the upper temperature limits for the growth of higher plants, such as grasses, growing in the hot soil about thermal springs are in general similar to those reported by Löwenstein for Mastigocladus is indicated by observations made by Mrs. Brues, but as yet unpublished.

The Nature of Heat Susceptibility

To account for the great differences in tolerance to high temperature as well as to certain poisons, Mereschkowsky ('10) conceived the rather startling theory that there exist two types of protoplasm in living organisms. This innovation has received scant recognition at the hands of biologists, but as it appears to be quite plausible in connection with some of the facts outlined in the present account, I think it deserves some further discussion. He assumed in brief that animal cells and those of higher plants represent symbiotic associations while the protoplasm of bacteria and most fungi is of a single primordial type. The animal cell is a single symbiotic association with a "Micrococcus" which forms the nucleus while the plant cell is a double symbiosis of protoplasm, nucleus and "Haplobacteria" which become the chloroplasts. Thus a mycoplasma of simple type is present in bacteria and Cyanophyceæ, and a complex, symbiotic type is characteristic of the higher plants and of all animals. One of the main distinctions between the mycoplasma and the animal type or amœboplasma lies in the great resistance to high temperatures exhibited by the former.

The distinction based on the resistance to high temperatures would appear to be broken down by the resistance of certain encysted Protozoa to high temperatures[1], and as a matter of fact among bacteria alone we find both heat-susceptible and heat resistant types. Recent studies also tend to disprove Mereschkowshy's conception of the structure of the bacterial cell.

More recently another type of intracellular symbiosis of bacteria or fungi with insects and other animals has been shown by a number of workers (*cf.* Buchner '21) to be quite widespread, but this is so clearly an independent and specialized development that it has no bearing on Mereschkowshy's conception. However, the latter was revived a few years ago by Wallin ('23; '27) with reference to the

[1] See postscript, p. 228.

mitochondria which he regards as microörganisms living symbiotically in the cells of both plants and animals. In this conception, the mitochondria are the only symbionts, giving rise to the chloroplasts of the higher plants and a single or binary symbiosis exists in both animal and plant cells. At first blush this theory appears to accord very well with some of the facts observed in thermal animals and plants. The presence of mitochondria does not appear to have been demonstrated in bacteria and the blue-green algæ, and these two groups of organisms are those which exhibit the greatest resistance to heat. They are in fact the only organisms in hot springs which may have persisted in such an environment from the early stages in the earth's history, since I have already shown that the animal life of hot springs includes only a series of highly specialized forms derived from fresh water. Thus what we may regard as the primordial types of organisms in hot springs are the groups apparently destitute of mitochondria. Furthermore, the mitochondria are very susceptible to heat and their disintegration appears visibly to take place at temperatures close to those which are fatal to organisms provided with them, that is in the neighborhood of 48–50°. We would appear, therefore, to have here visible evidence of a disintegration of mitochondria coincident or very nearly so to the onset of irreversible changes induced by heat which indicate the threshold of destruction of living tissues by heat. In the absence of other evidence it is therefore quite probable that the heat suceptibility of organisms is due to its effect upon their mitochondria, especially as these bodies are extremely susceptible to other chemical and physical changes. Even in their staining reactions, they behave very differently from the chromatin and other constituents of the cell, and as Zirkle ('28) has shown, their staining properties are greatly changed by differences in the hydrogen ion concentration of fixing agents.

Such a conclusion, does not, however, entail any necessarily symbiotic relationship on the part of the mitochondria although it does very strongly suggest that it is the thermal sensitivity of these granules which determined the reaction of tissues or entire organisms to heat. Some support to this assumption is given by reactions of certain flagellate Protozoa to heat described on a previous page (p. 161). Accompanying the irreversible changes in animal tissues which lead to injury or death from heat, there are always certain visible changes of a physical nature which result in heat rigor. These appear to be in the nature of a coagulation or change in the fluidity of the protoplasm or of certain tissues. These temperatures, as already pointed out are closely coincident with the temperatures at which the mitochondria are destroyed.

Body Temperature

In my earlier paper ('24) there is included a number of references to the body temperatures of non-aquatic insects, but I failed to touch upon one important matter in connection with the body temperature of the social hive-bee which is of great interest.

This highly social insect has become modified in several particulars with reference to community life. In common with other social insects it has developed, quite independently, however, a sterile worker caste like that of the termites and ants and in connection with the development of extensive colonies has found it necessary to occupy a domicile to house the thousands of individuals which form each family. With this massing together of individuals an opportunity has presented itself to this poecilothermic animal to acquire some of the advantages enjoyed by warm-blooded animals. Thus in the winter when the air temperature and consequently that of the nest or hive becomes greatly lowered, the bees institute a series of calisthenic exercises which serve to raise the temperature of their bodies above that of the surrounding medium. Enclosed in a hollow tree or artificial hive the temperature of the swarm promptly rises and the bees are able to maintain a temperature far more uniform than that of other non-gregarious insects, and by so simple an artifice to become at least partially warm-blooded animals.

The body temperature of the hive-bee has received careful investigation by Brünnich ('19), the temperature of the colony has been studied by Gates ('14) and the temperature of the honey-bee cluster in winter by Philipps ('14).

Brünnich determined the body temperature with a minute thermocouple, and found that it sometimes reached an extremely high level. Thus he found the temperature of the worker reaching 39.6°, that of the drone 48.4° and that of the developing brood 45.2° at times when the outside air was far lower (12–17° C. or 53–62° Fahr.). In the honey-bee cluster, Philipps never found the winter temperature to rise above 33° and even in warmer parts of the year Gates found that it did not rise above 36°. The body temperatures of the bees and brood would therefore appear to be much higher than that of the hive and clusters. It really seems, however, that further data should be collected to determine whether the body temperatures of bees are normally so high as those found by Brünnich.

The hive-bee appears to be entirely exceptional among insects and probably among pœcilothermic animals in general in regulating the temperature of its body and dwelling by concerted action during

cold weather. Such activities do not seem to have been recorded among ants and termites as the latter passively allow themselves to succumb to the benumbing effects of the cold at the approach of the cold season. Their body temperatures during the hibernating season are undoubtedly slightly higher than those of solitary insects due to the heat produced by metabolism in a number of individuals closely confined or huddled together, but there can be but little rise in temperature compared with that produced in the beehive. Similarly in masses of hibernating beetles, such as certain coccinellids which collect in great masses during the winter season, the temperature of the mass is known to be considerably above that of the surrounding soil or air.

The normal body temperatures of birds are of particular interest in connection with the thermal environment, since these animals maintain temperatures considerably above those encountered among mammals. According to Wetmore ('21) who has presented a very extended discussion of the temperature in birds, it seems probable that there has been a progressive rise in body temperature in the evolutionary development of the birds. There appear to be numerous exceptions to this, but in general the lower temperatures are encountered in the more primitive families and the higher ones in the more advanced families. He says (*loc. cit.*): "Thus grebes, the totipalmate groups (Anhingidæ, Phalacrocoracidæ and Pelicanidæ) and herons are in general low in average body temperature, while gulls, shorebirds, pigeons and cuckoos are high." It is evident from the extensive tables given by Wetmore that temperatures of 108°–109° Fahr. (42.2°–42.7° C.) are normal for many birds and that 110° Fahr. (43.3° C.) is quite normal for a few forms. Higher temperatures have been at times reported, but some of these have no doubt been due to febrile disturbances induced possibly by avian malaria or other infectious diseases. The highest single reading which Wetmore believes to be valid is 112.7° Fahr. for an individual of the western wood pewee (*Myiochanes richardsonii*) this is however only 1.7° above the mean normal for this species. It seems indeed, rather surprising that higher temperatures should not have been occasionally encountered in sick birds. I think one may be quite justified, in the absence of higher records among birds averaging 108°–109°, to believe that these animals live so near the upper lethal temperature limit that they are unable to withstand so great a rise in temperature as may be endured by mammals like man where a rise of 5°–6° Fahr. occurs commonly without serious sequælæ.

The Brackish Water Fauna in Relation to That of Thermal Waters

Buxton has recently expressed the opinion ('26) that the colonization of the sea by insects has been held in check not by the physical factors in the environment, such as currents, tides, waves, etc., but by the salinity of the sea and "the presence of a variety of inorganic salts; it may be that magnesium salts or sulphates or other substances are incompatible with the life of certain aquatic insects." Since a few insects have been able to overcome such barriers, he believes that other matters, such as the presence of different kinds of enemies and the lack of the ordinary diet of phytophagons insects act as barriers and that it is the failure of insects to overcome more than one type of barrier that has doomed them to practical exclusion from the sea.

The dearth of insects in the sea has long been recognized and has received much comment, and the scarcity of marine insects is in fact almost pronounced as the lack of sponges and Cœlenterates in fresh water.

Naturally, most observers have seized upon the one constant peculiarity of the sea as the determining factor and have assumed that the salinity of the water is the exclusive, or at least the only influence worthy of consideration, and there is much to support this view.

There has in the past been much speculation as to why it is that some fresh water animals are able to exist temporarily or permanently in brackish or salt water and *vice versa* why certain marine forms may adapt themselves to estuarine or freshwater existence. Bert ('73; '83). Loeb ('03), Quinton ('04) Fredericq ('04); '22) have dealt with various matters relating to these phenomena which appear to be rather complex and to depend upon several factors. A change of medium causes either a loss of weight when fresh water animals are removed to water of greater salinity, or a gain in weight when marine animals are transferred to water of reduced salinity. The ability to survive such changes of medium is by no means uniform among various invertebrates, but varies within wide limits in the case of both fresh water and marine species. The body fluids of marine invertebrates are of practically the same concentration and composition as sea water, and they quickly change in response to changes in the medium to the point of osmotic equilibrium. On the other hand, fresh water forms have a lower osmotic pressure than that of marine ones, and they are able to maintain this, preventing a further dilution of the blood. Adolph ('25) believes from experiments of his own and

of others that the possibility of survival of fresh water invertebrates in brackish or salt water depends directly upon the osmotic pressures of their body fluids. As this varies considerably, from about 12 to 50% that of sea water, we should expect their resistance to salinity to vary in a corresponding degree. Thus he found that the crustacean *Gammarus fasciatus*, is able to survive in sea water while some other forms (a flatworm and Paramœcium) can withstand only one-third or less the concentration of sea water. This is particularly interesting since Gammarus is one of the common types found in waters of greatly varying salinity. Duval ('24) has similarly noted a great difference in in the composition of the body fluids in crabs (cf. Brues '27[b]) and Kemp ('15) has noted great differences among crabs in their ability to invade estuarine waters.

That these experimental data may explain the great delicacy of adjustment of various insect larvæ to slight differences in salinity of the medium cannot be granted, however. They show that the limiting factors may vary within wide limits and this forms a physiological basis for an understanding of the readiness with which some fresh water animals may invade marine or estuarine or saline habitats. As we have seen such types among insects are very clearly restricted to particular groups. For the change from marine to freshwater life which we must grant occurred originally in the case of all fresh water groups, and has taken place more recently in scattered cases there seems at present to be no adequate explanation. The great similarity between the fauna of thermal waters and that of brackish water to which I called attention in my former paper ('24) is again fully demonstrated by the collections discussed in the present account and serves to show that aside from temperature the most important single characteristic of thermal waters which determines the nature of its fauna is the presence of salts in solution. Almost universally these are present in sufficient amounts to increase the osmotic pressure of the medium very appreciably.

The Temperature Range of Individual Species

A large mass of data has been presented in the preceding account indicating the actual temperatures at which a number of species have been observed to occur, and these indicate clearly the upper temperature limits of life for individual species and groups of related forms. Since many of these thermophilous organisms occur generally at the lower temperatures characteristic of non-thermal waters, they demonstrate that the thermal environment for such organisms is simply an extension of a more ordinary one. In the case of many

bacteria and blue-green algæ it is equally evident that there are species of these groups which are restricted to higher levels of temperature at least so far as growth is concerned. Among animals, the number of thermophilous species dependent upon abnormally high temperatures for their existance is very small and at the present state of our knowledge it is difficult to pick out with certainty any number of forms which are thus restricted. This is due mainly to the small size of the springs that support the thermal fauna which prevents the occurrence of graded temperature series under comparable conditions.

At only one place in the world has it been possible to follow the changes in composition of the thermal fauna over a considerable range in water from a single source. This has been done at the thermal springs of Meskhoutine, or Hammam Meskhoutine in northern Africa. The French naturalist, Blanchard ('03) published a very interesting account of the fauna of these springs which had previously been considered by several others and has since been dealt with in detail by Seurat ('22). These springs are of very large size, yielding between 400 and 500 gallons of water per minute or about 100,000 litres per hour at a high temperature between 78° and 95°. Descending the stream arising from these springs where the water has cooled to 60° there are many dark green algæ, but no animal life. At 51° the crustacean, *Cypris balnearia* first appears. At 45° this Cypris becomes very abundant and frogs jump into the water when disturbed, but do not remain there voluntarily. At 44° Cypris is still abundant while the fresh-water crab, *Telphusa fluviatilis* and tadpoles of the frog, *Rana esculenta* appear. Adult frogs are numerous, entering the water and staying there quite willingly. At 43° Cypris becomes more rare; annelids of the genus Näis appear while frogs and their tadpoles remain abundant. At 39° the Cypris has disappeared and according to Blanchard occurs only between 43°and 51°. Below this temperature the fauna gradually becomes normal just as I have indicated in a composite way with reference to the water beetle fauna of our western hot springs (see p. 178).

From Blanchard's observations there is no doubt that *Cypris balnearia* is restricted to a definite range of temperatures above 40°. To this may be added also the acarine genus *Thermacarus* mentioned on a previous page. Here two species are concerned one from Eastern Asia and another from the Western United States, both found only in hot springs and furthermore representing the only known species of a genus which constitutes by itself a distinct family of hydracarine mites.

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POSTSCRIPT.

It will be noted by the reader that no consideration of the crustacean fauna of hot springs is included in the foregoing account. Rather extensive collections were made, but it has not been possible to work over this material in time for inclusion in the present report.

In connection with the effects of heat upon encysted Protozoa, more recent work shows that these animals cannot survive the temperatures reported by Boeck which I have quoted on p. 160. This investigator tested the living condition of the cysts by their staining reactions, and this method does not appear to be reliable. Consequently, these encysted Protozoa do not form an exception to the general relations of animal life to high temperatures.

PLATE I

Above

View of the siliceous sinter terrace at Beowawe, Nevada, looking toward the southeast from the desert floor. The geysers and hot pools are on the nearly level upper surface. The regular flow of water is indicated by dark streaks on the slope caused by the presence of algæ.

Below

View from upper part of same terrace, looking westward over the valley. The springs at the foot of the terrace are visible near the center of the photograph with the darker, green area which they water.

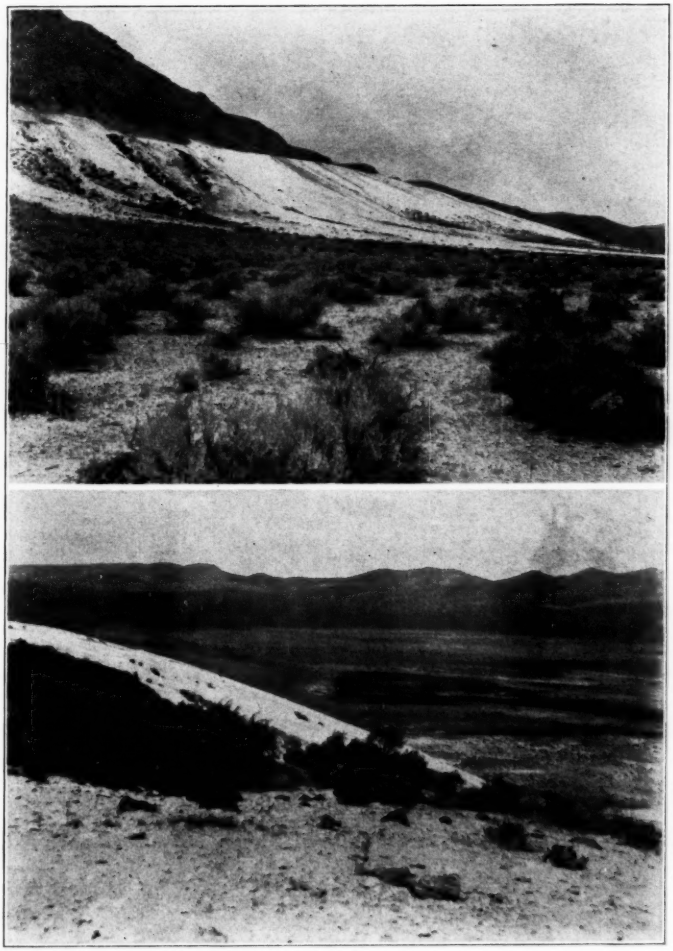

PLATE II

Above

Basins of part of a group of extinct hot springs near the western shore of Pyramid Lake, Nevada. These rise above the level of the surrounding surface from eight to twelve feet.

Below

Hot Spring No. 7 at Minden, Nevada. The springs are in the foreground and on the slope at the right.

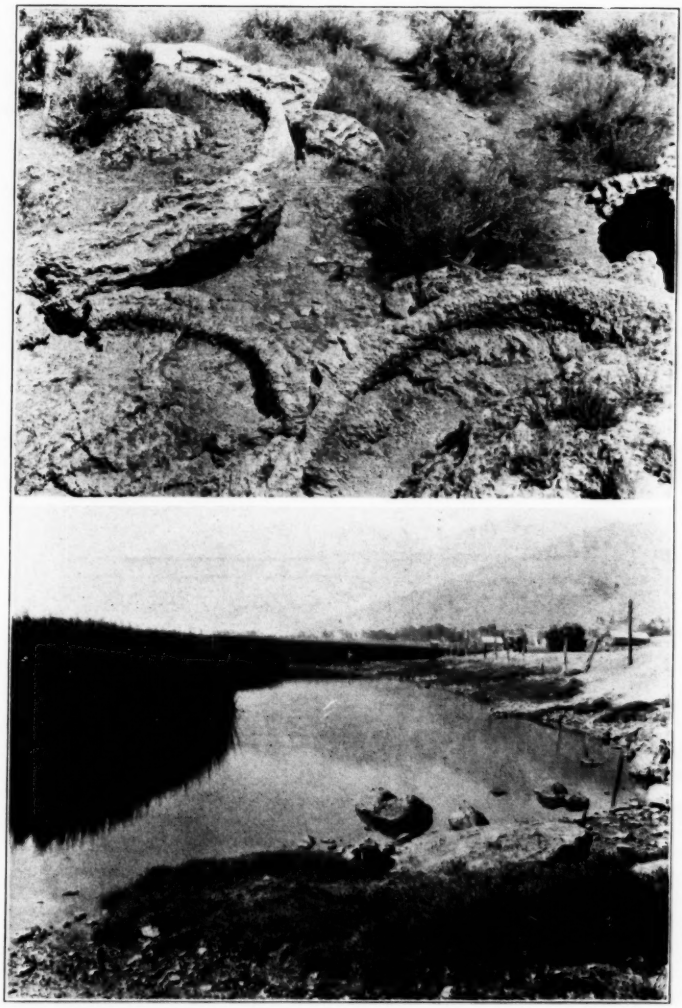

PLATE III

Above

Large pool on upper surface of deposits from Hot Spring No. 21 at the northern end of the Osobb Valley, 72 miles south of Winnemucca, Nevada. The surface of this mound rises about 60 feet above the floor of the desert valley.

Below

Overflow from Hot Spring No. 23[a], 37 miles south of Battle Mountain, Nevada. The spring lies beyond the photograph on the left.

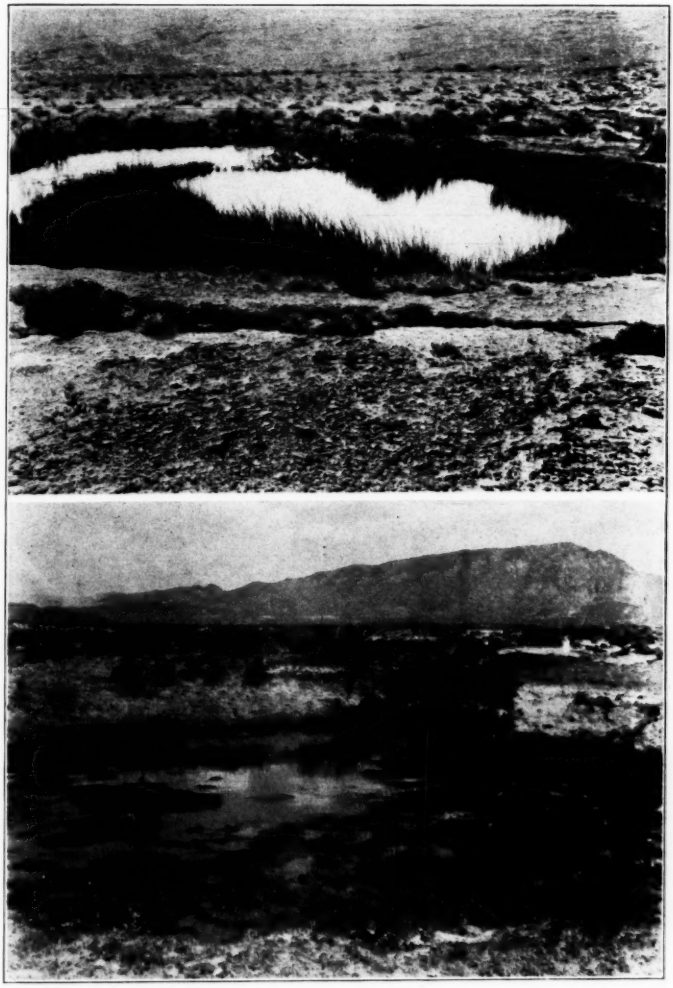

PLATE IV

Above

Mud pot or steaming vent from which there is no flow of water, in the Devil's Kitchen, near Drakesbad, Mount Lassen National Park.

Below

Edge of pool formed by overflow from Hot Spring No. 17, twenty-one miles south of Denio, Oregon.

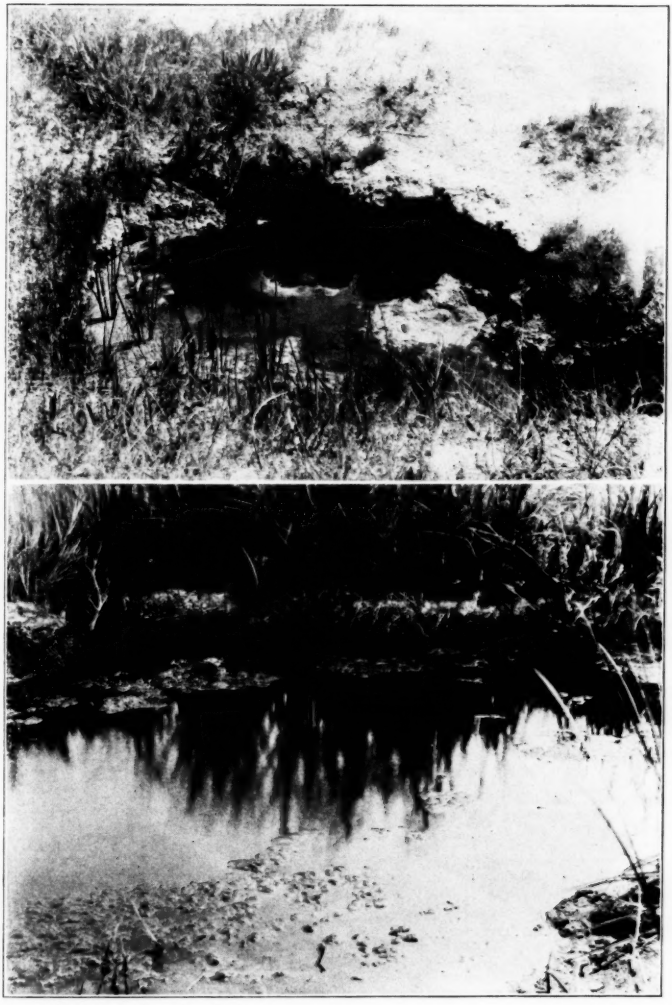

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PLATE V

At Left

Part of mound built up by Hot Spring No. 19 at Paradise, Nevada. The internal structure is visible as the spring has been tapped to supply water for irrigation purposes.

At Right

One of the small overflow streams on the slope of the terrace at Beowawe, Nevada (Hot Spring No. 24). The dark color is due to the presence of algæ.

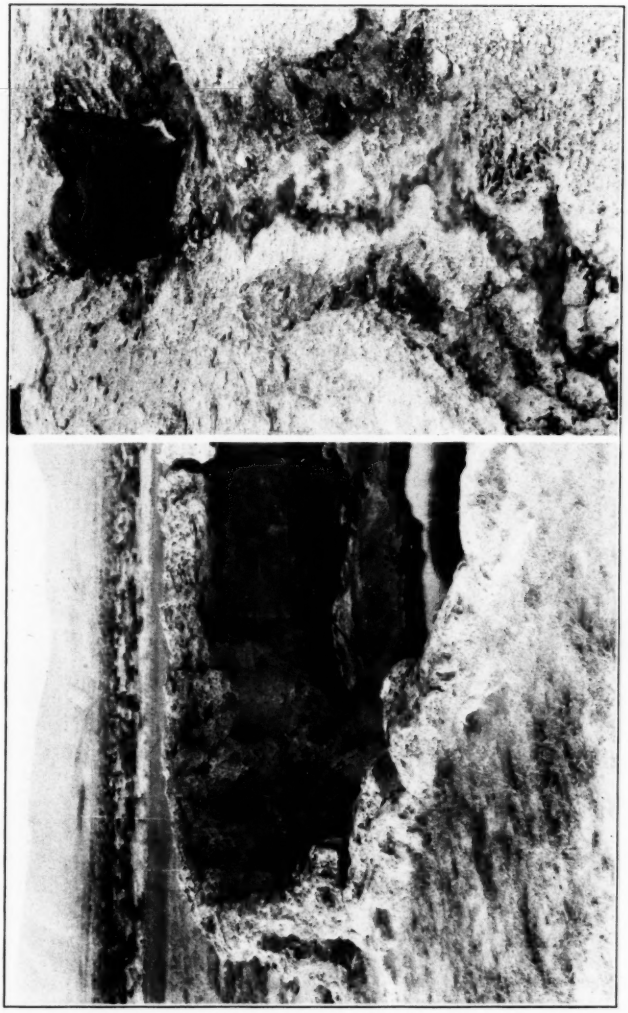

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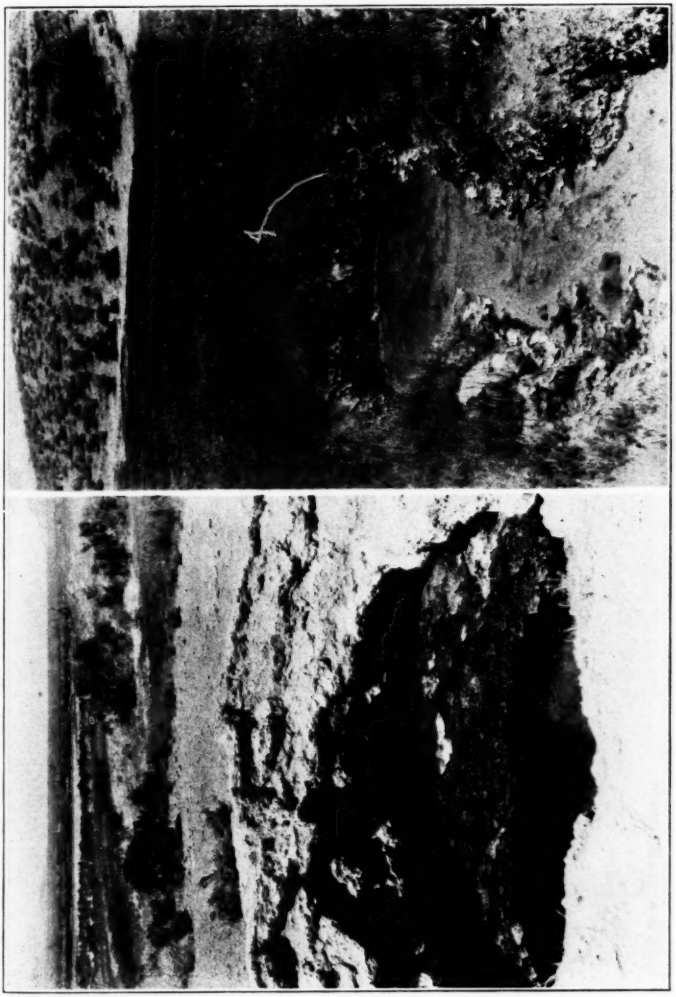
PLATE VI

At Left

View of sinter mound built up by Hot Spring No. 23[a], 37 miles south of Battle Mountain, Nevada. As the spring has been tapped near the base of the mound, the water level is well below the natural orifice. Rising bubbles of gas are visible in the foreground.

At Right

One of the smaller springs in the group of Hot Spring No. 20, twenty-nine miles south of Winnemucca, Nevada.



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